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THESIS

A CHEMICAL WARFARE MODULE FOR THE AIRLAND ADVANCED RESEARCH MODEL (ALARM)

by

Layne A. Van Arsdale

December 1987

Thesis Advisor: Samuel H. Parry

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A Chemical Warfare Module for the AirLand Advanced Research Model (ALARM)

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ABSTRACT

This thesis incorporates an explicit depiction of chemical warfare (CW) in the AirLand Advanced Research Model (ALARM) being developed at the Naval Postgraduate School based on the Army's AirLand Battle doctrine. The CW module centers on a planning algorithm using the generalized value system (GVS) for future state decision making. The planning algorithm comprises the Commander's Estimate of the Situation. The GVS quantifies capabilities and importance of all battlefield entities. The CW module represents key chemical staff functions. The algorithm's decision rule is extended, adding aspects of utility theory. The basic concepts of the module are demonstrated in an application computer program running a combat scenario. The program generalizes previous development work on the GVS and the planning algorithm, producing a plan consisting of the courses of action of greatest value in performing the mission. Its interactive structure provides the basis for a staff training aid or decision support system.

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I. INTRODUCTION

A. PURPOSE

The purpose of this thesis is to extend the development of the AirLand Advanced Research Model (ALARM), an on-going effort at the Naval Postgraduate School, by incorporating an explicit depiction of chemical warfare (CW). The chemical module functions as a surrogate for the headquarters chemical staff sections from battalion through corps by analyzing effects of enemy chemical employment, "advising" the commander of appropriate actions, planning and directing CW defense, and planning friendly chemical retaliation. A computerized application demonstrates the logic framework of the module and provides a basis for an interactive training and planning aid for field commanders and their staffs.

B. BACKGROUND

1. AirLand Battle

ALARM is a developmental model for new concepts in combat modeling which can be used in evaluating the US Army's AirLand Battle doctrine [Ref. 1]. The Army's Training and Doctrine Command developed AirLand Battle doctrine as a response to changing technology and operational conditions, especially in NATO. The future battlefield is envisioned as having relatively indistinct battle lines, with boundaries between front and rear areas

being blurred, as attacking forces penetrate or bypass forward defenses in order to divide, disrupt, demoralize, and quickly defeat their opponents. AirLand Battle postulates the use of depth, initiative, agility, and synchronization to defend against intense, numerically superior attacking forces. Besides holding off attacking forces in direct contact, operational level commanders must strike in depth against supporting units or approaching units that are not yet committed. By delaying, damaging, or destroying uncommitted units, the enemy's timetable is upset, alternatives are taken away from the enemy commander, his organization is disrupted, and the attacker's initiative is lost. Obviously, with limited assets for such deep strikes, those enemy units whose delay or destruction will provide the most benefit must be identified, located, and attacked before others [Ref. 1].

2. ALARM

Initially, ALARM will be a systemic model (no man-in-the-loop interaction). This is intended to allow more consistency, control, and predictability in decision making and more timely results. It also means that decision making must emulate, as closely as possible, human decision processes. As currently being developed, ALARM will model the BLUE planning and order functions, with interfaces to an execution model. The as-yet unspecified execution model will depict the physical conduct of the battle. It will

respond to orders provided by ALARM and provide situation reports and updates to ALARM for further planning and order preparation. In a sense, then, ALARM will perform multiple level command and staff functions, from battalion through corps, with the execution model adapted to ALARM actually "fighting" the battle [Ref. 2].

One of the key concepts being developed for ALARM, to enable planning for the battle in general and for the deep strikes called for by AirLand Battle doctrine, is the Generalized Value System (GVS) [Ref. 3].

The GVS has two innovative features upon which ALARM hinges. First, all entities in the model, whether combat units, support units, key terrain, or man-made objects, will have comparable units of measure of their value. The common unit of value is the Standard Power Unit, or STAPOW. An entity's total power is the sum of its inherent and derived power. A combat unit has predominantly inherent power, due to its ability to directly disrupt, delay, or destroy the power of enemy entities. Support units and other entities have mostly derived power based on their ability to increase or maintain the inherent or derived power of other friendly entities.

The basic power of each entity is adjusted to account for such situational factors as personnel and equipment status, mission, location, and speed of movement. Situationally adjusted power allows for the fact that an

entity's value depends on its state, the specific combat situation, and the differing perspectives of commanders at different organizational levels. This common, adjustable metric allows the application of the second feature of GVS: future state decision making. In most current models, the only information available to the human decision maker is the prevailing status of engaged combat forces. Then the decision maker has to project this information mentally to compare possible future states in order to plan. The GVS provides mathematical relationships that predict the state of any entity at any point in time, in STAPOWS. This makes it possible to attempt to model decision making based on AirLand Battle doctrine.

3. Chemical Warfare

Employment of chemical agents by the Soviet Union or its surrogates has been documented over much of the world in recent years. Soviet doctrine makes CW a standard tactical tool for their commanders. Soviet equipment and training facilitate its use. Chemical weapons are easily produced and their use by Third-World countries such as Iraq and Iran has also occurred. The threat to the US and its allies is clear [Ref. 4].

Two major factors, however, have led the US military to be inadequately prepared to deal with CW. First, US forces have not experienced large scale employment of chemical weapons against them since World War I. Second,

the effects and rigors imposed by CW can make the subject seem "too hard." Thus CW has often been put off, assumed away, or ignored in military analysis, planning, and training in order to be able to deal with other aspects of warfare.

This situation has typically manifested itself in combat modeling in the following ways:

- Ignoring CW; staying conventional.
- Playing CW manually, off-line (especially training models).
- Adding on inadequate CW modules, after the model has been designed, leading to weak interfaces with the rest of the model and making it easy to "turn off" CW or ignore it, usually with little or no penalty.
- Contriving special purpose CW models, with weak depiction of other aspects, leading to questionable results and lack of usefulness in combined arms studies.

Failure to include CW conditions in planning and modeling where a chemical threat exists is unrealistic and potentially dangerous. CW must be treated as a condition of the battlefield to be dealt with along with all other factors.

The ALARM offers a unique opportunity to integrate CW beginning with the model's early development. The GVS is particularly well suited to the analysis of CW. For example, future state decision making is specifically intended for allocating scarce assets such as chemical munitions and chemical defense units. ALARM will also eventually permit an analysis of the effects of CW on

logistical units and facilities, by using the GVS through the application of derived power.

A technical and doctrinal summary of chemical warfare from US and Soviet perspectives is at Appendix A.

C. ORGANIZATION OF THE THESIS

1. Methodology

Kilmer [Ref. 3] provides the basic development of the GVS. Using these concepts, Fletcher [Ref. 5] proposes a planning algorithm for ALARM. This thesis provides a structure for a chemical warfare functional module available to the planning modules at each organizational level. The application example is based on Fletcher's algorithm, and extends some of the concepts discussed by Kilmer.

The chemical battle is decomposed into its defensive and retaliatory components. The decision logic required to survive and fight in a chemical environment is incorporated into ALARM's planning process. In addition:

- Interfaces required with other ALARM modules are identified.
- Parameters required to be included in the input data base are identified.
- Mathematical relationships depicting CW effects are developed from the GVS, gaming, optimization, and decision theory techniques.

A computer program is presented demonstrating the application of the CW module in a combat scenario. The program generalizes Fletcher's program implementing the ALARM planning module [Ref. 5] and adds the components of

the CW module. User-interactive data input represents calls to the ALARM data base, other planning functions, or other functional modules. This approach provides an additional potential use for the program as the basis for a planning and training aid for field commanders and their staffs. The model also extends Kilmer's theoretical considerations of value by applying them explicitly in Fletcher's decision rule.

2. Scope and Outline

The chemical module performs CW analysis and planning at all organizational levels depicted by ALARM, battalion through corps. Headquarters chemical staff functions at each level are modeled, plus physical effects modeling to accomplish the required decision tasks and feed orders back to the execution model.

Chapter II provides a description of ALARM and the GVS as necessary to understand development and application of the CW module.

In Chapter III the CW module is described with its application of the GVS and incorporation into ALARM.

Chapter IV presents the computerized application of the module in a combat scenario. Results of the planning simulation are presented and discussed. These show the utility of the program in a scenario incorporating chemical warfare conditions.

Chapter V offers conclusions and discusses additional work indicated for further development of ALARM and the CW module. The results of the application program indicate the successful integration of CW into the ALARM concept. Further work in refining and expanding the CW module and developing the program as a stand-alone application is indicated.

Appendix A provides a background summary of CW and the computer program application of the model is at Appendix B.

II. ALARM AND THE GVS

A. ALARM

The AirLand Advanced Research Model is being developed as a systemic (no man-in-the-loop interaction) corps-level model. The architecture allows man-in-the-loop if desired.

The primary purposes of ALARM are to:

- Develop modeling methodology for very large scale and sparsely populated rear areas.
- Use the methodology in wargaming and simulation with initial emphasis on interdiction.
- Perform research on AirLand Battle concepts. [Ref. 6]

The systemic nature of ALARM dictates that its decision making processes emulate human decision processes as closely as possible. A combination of decision methodologies follows human decision procedures more closely than previous models. Threshold values are used to determine when planning or decision making activities should be executed. For example, when the difference in power between forces exceeds the feasibility threshold, a plan must be made to restore feasibility. Decision rules are used to limit alternatives. Network methodologies itemize alternatives and expected value criteria are used to make a decision. [Ref. 2]

Current ALARM development is focused on the planning model. Command and staff functions at battalion through

corps are represented. A separate execution model will be adapted to model the conduct of the battle providing combat results, battlefield intelligence, and response to the planning model. At each organizational level, the planning model receives orders from the next higher level and, using the assets provided and its perceived situation, prepares a 'macro' plan for the commitment of units over time to accomplish the mission. The macro plan is used to generate orders to the next lower organizational echelon. During the course of the battle, if the macro plan becomes infeasible, thus threatening defeat, micro planning is accomplished. Micro planning makes decisions on an immediate basis in order to adjust the initial plan and avoid losing the battle. If necessary, assistance is requested from the next higher level.

Three unique methodologies are used by ALARM to perform the decision function:

1. A time domain network handles the planning function to develop high level mission requirements for subordinate units. Arcs on the network represent the time required to accomplish the activity represented.

2. A framework of layered Cartesian space networks represents physical connections between points on the battlefield. Three networks identified to date are:

   - Terrain and transportation network.

   - Communications network.

   - Logistics resupply network.

3. The Generalized Value System (GVS) quantifies the capabilities and importance of all entities on the battlefield at some future time. [Ref. 2]

The singular thrust of ALARM is to model those procedures used by real commanders and staffs to develop plans for the commitment of units and the use of other assets.

B. THE GVS

This section provides a summary of Kilmer's concepts [Ref. 3] as expressed in Fletcher's planning model [Ref. 5], necessary for the development of a chemical module. Concepts from both efforts are incorporated and extended in the CW module. Future state decision making using the Generalized Value System is the key to the planning process in ALARM. The basis for these procedures is the quantification of the capability of military organizations in terms of the power and value of any entity on the battlefield, in common Standard Power Units, or STAPOWs. Based on the current perceived situation, the power and value of entities can be forecast over time, using combinations of exponential functions expressing the growth or loss of power. These functions include realistic terms expressing both enemy and friendly influences on a unit's power.

An entity's total power is the sum of its inherent and derived power, measured in STAPOWs. Many entities will have only inherent or derived power, others may have both.

Inherent power is the ability to disrupt, delay, or destroy the enemy, as direct combat power. Derived power is the ability of an entity to change or maintain the inherent power of other entities. For example, combat units such as a tank battalion will have inherent power. Entities such as bridges or supply units will have derived power.

Inherent power is expressed in several ways, relating it to the situation over time. Basic inherent power (BIP) is the inherent power of a unit at full strength, in position to accomplish a mission against its most likely opponent. The BIP for each entity is a derived model input [Ref. 3], such as firepower scores. Work is planned at the Naval Postgraduate School within the next year to systematize and quantify a catalog of BIP values. The position at which a unit achieves its maximum power is determined for each situation based on its mission and information from the transportation network. The adjusted basic inherent power (ABIP) is the BIP of a unit adjusted for its actual mission and condition (STATE), discounted to present time (prior to the accomplishment of the mission). The function is:

$$ABIP_i = BIP_i \times (K_{i,m}/DIST_i) \times f(STATE_i) \qquad (2.1)$$

where:

$K_{i,m}$ is a factor associated with the mission, m, assigned to unit i,

$DIST_i$ is the distance of the unit at the present time from the position where the mission is to be accomplished,

$STATE_i$ is the condition of the unit, expressed as a vector of the percentages of equipment and personnel that unit i possess at the present time, t_p, and

$f(STATE_i)$ is a function of the unit's condition resulting in a value between 0 and 1.

The $f(STATE_i)$ used in the application later is the square root of the product of the percentages of equipment and personnel on hand as a description of the readiness of the unit. Therefore, ABIP is the measure of the power of a unit at the beginning of the planning time period, $t_p < t_{a,i}$, where $t_{a,i}$ is the time at which entity i is calculated to arrive in position to perform its mission. The time of arrival, $t_{a,i}$, is given by $DIST_i/SPEED_i$, where $SPEED_i$ is the average speed at which the unit is able to move along the minimum time path of the transportation network to its position.

The situational inherent power (SIP) of an entity is the forecasted inherent power for time, t. It is assumed that, without attrition, as a unit comes closer to performing its mission its power increases exponentially over time.

$$SIP_{i,t} = ABIP_i \times \exp(D_i \times (t-t_p)), \quad t_p \le t \le t_{a,i} \qquad (2.2)$$

where:

D_i is the rate at which power increases from t_p to $t_{a,i}$:

$$D_i = (\ln(SIP_{i,t_{a,i}}/ABIP_i))/(t_{a,i}-t_p) . \qquad (2.3)$$

Computationally, $SIP_{i,t_{a,i}}/ABIP_i = DIST_i$. This substitution is used in the module application computer program.

Similarly, after a unit is in position to accomplish its mission, it is assumed that, without resupply and again without attrition, its power will decay exponentially over time due to its consumption of resources:

$$SIP_{i,t} = SIP_{i,t_{a,i}} \times \exp(-U_{i,m} \times (t-t_{a,i})), \quad t > t_{a,i} \qquad (2.4)$$

where:

$U_{i,m}$ is the resource usage rate of unit i with mission m.

When a unit engages an enemy unit j, its power is further reduced by an attrition rate $ATT_{i,j}$:

$$SIP_{i,t} = ABIP \times \exp((D_i-U_{i,m}-ATT_{i,j}) \times (t-t_p)), \quad tp \leq t \leq t_{a,i} \qquad (2.5)$$

$$SIP_{i,t} = SIP_{i,t_{a,i}} \times \exp((-U_{i,m}-ATT_{i,j}) \times (t-t_{a,i})), \quad t \geq t_{a,i} \qquad (2.6)$$

Equations 2.5 and 2.6 are general forms and may be adjusted for specific cases based on the situation or the time of application. The exponential factors may be adjusted with time as well. For example, if a unit is engaged by more than one enemy entity at various times, the sum of the enemy units' attrition rates is applied to the power computation at the times at which they apply. The resource usage factor, U, may be adjusted for various phases of an operation.

Applying these equations to the development of a unit's power over time results in a curve such as the one shown in Figure 2-1.

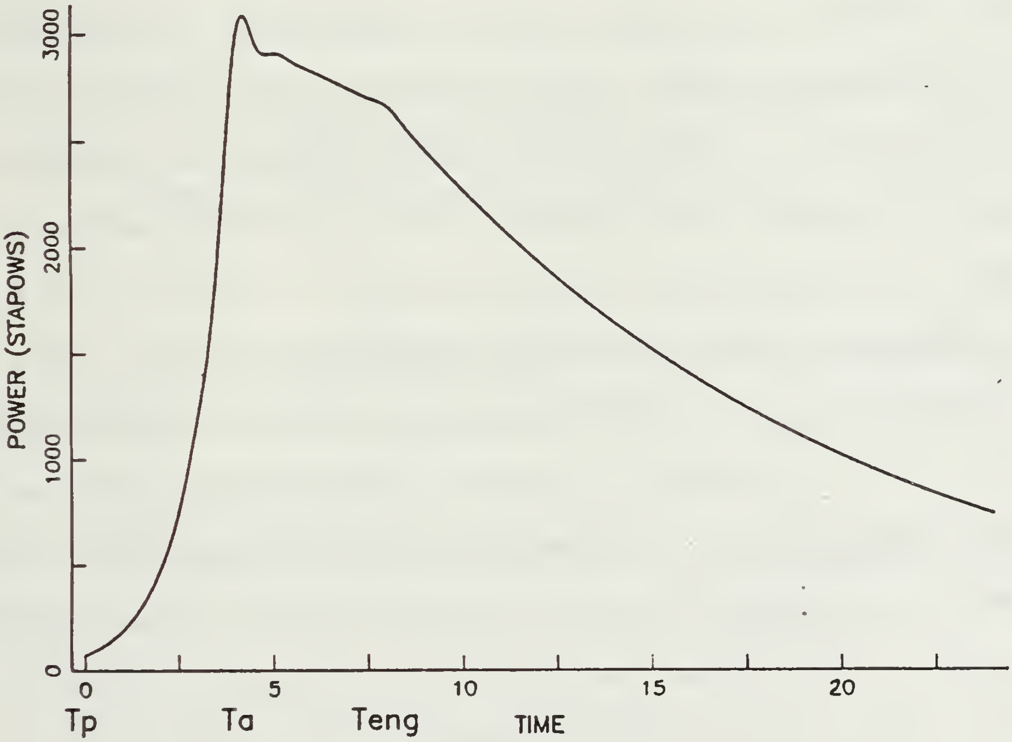

Figure 2-1 Example of the Power Curve of an Entity

C. THE PLANNING ALGORITHM

The planning process begins with receipt of an order in the form of a macro plan from the next higher organizational level. Fletcher's planning algorithm consists of a modified estimate of the situation used by Army commanders to decide how best to accomplish the mission [Ref. 5]. The steps of Fletcher's algorithm are:

- Determine initial mission feasibility.
- Designate the decision point.
- Develop feasible courses of action.
- Select a course of action to restore feasibility at the decision point.
- Repeat until feasibility is restored throughout the planning period.

Using the GVS equations, plan feasibility is predicted based on friendly (blue) force versus enemy (red) force power comparisons. The process also determines whether a plan will accomplish the mission and with what combination of assets.

1. Determine Initial Mission Feasibility

Feasibility is determined by whether a threshold interval of the difference in power between blue and red is maintained throughout the planning period, given an initial commitment of friendly units to the forward edge of the battle area. The model developed by McLaughlin [Ref. 7] determines this initial positioning of forces necessary to fight the battle. For simplicity, each force's power is

computed as the sum of the power to subordinate units. Although eventually it will be necessary to ascertain the nature of any synergism that exists among entities in a force, for the present this assumption lends consistency and simplicity of determination to the model. Over the planning period from the present time, t_p, to its end, t_e, each unit's power is computed using variations of equations 2.2 to 2.6. Summing over all entities in each force results in a total SIP for each side. The difference between the power curves are determined for each time step:

$$DIFF_t = SIP_{x,t} - SIP_{y,t} \tag{2.7}$$

where:

$SIP_{x,t}$ is the total power for the blue force at time, $t_p \le t \le t_e$, and

$SIP_{y,t}$ is the power of the red force at t.

This difference is compared to the threshold value dictated by the mission. If the threshold, T, is violated, the initial plan is infeasible. An infeasible plan is illustrated in Figure 2-2.

This step of the algorithm is summarized as follows:

- Beginning at the present time, t_p, compute all $SIP_{i,t}$ and $SIP_{j,t}$.
- Compute $SIP_{x,t}(\Sigma_i\ SIP_{i,t})$ and $SIP_{y,t}$.
- Compute $DIFF_t$.

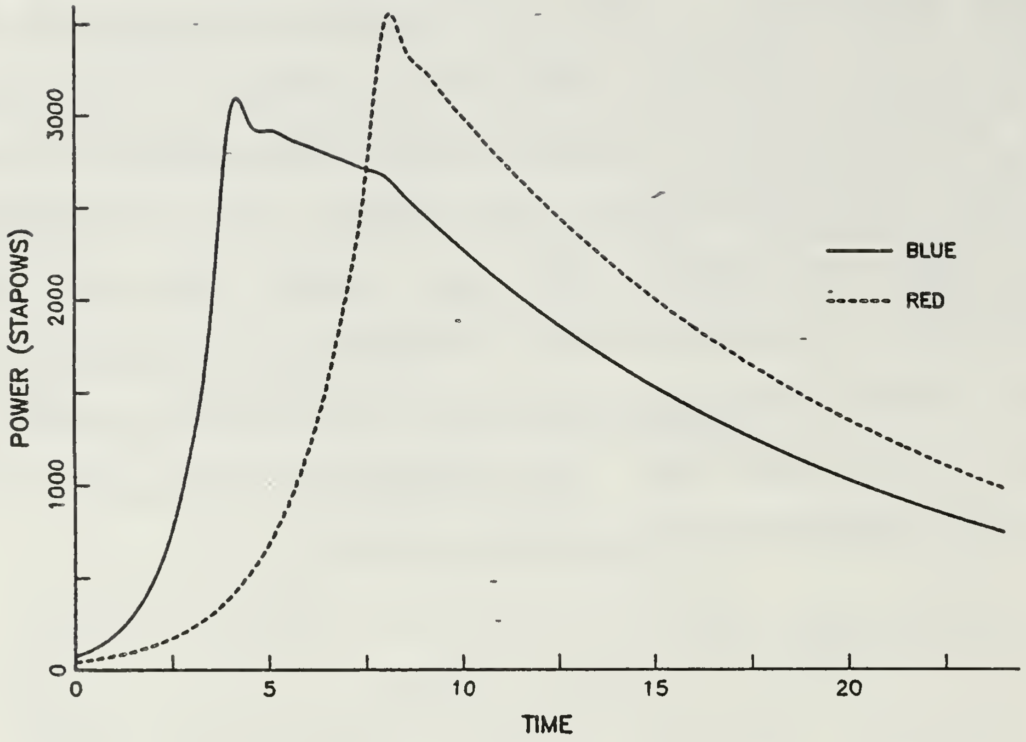

Figure 2-2 Example of an Infeasible Plan

- If $DIFF_t < T$, then $t = t_d$, the decision point.
- Increment t_p by t, the size of the time step, and repeat until $t = t_e$.

2. Designate the Decision Point

The decision point is the point in time at which the difference curve violates the threshold value. A decision must be made to commit previously uncommitted units at or before the decision point in order to decrease red power, delay it, or some combination of both. This will shift the infeasibility point to the right on the power curve or resolve it altogether. Therefore, the blue force has a period of time from t_p to t_d in which to decide which

uncommitted blue asset(s) to commit against which red units and at what time, t, in order to restore feasibility at t_d.

3. Develop Feasible Courses of Action

The planning algorithm calls for comparing the results of targeting each initially uncommitted blue unit against each red unit in each time step. It is assumed that each blue asset can carry out a mission against only one target at a time, so each asset-target-time combination is one possible course of action. Obviously, all such courses of action are not viable, however. Determination of viability includes notification and preparation time of the subordinate unit, range to the target, and commitment of the asset to a previously selected course of action. This step of the algorithm identifies for further consideration those courses of action which are viable:

- Beginning at the present time, t_p, for each blue unit i, for each type mission, if notification time plus t_p is greater than t_d, go to the next mission type, if all missions have been considered go to the next i.
- For each red unit j, if $DIST_j > RANGE_i$, go to next j.
- Compute $SIP_{i,t}$ and $SIP_{j,t}$ and store.
- Increment t by Δt and repeat until notification time plus t is greater than t_d for all i.

From the viable courses of action, those which restore feasibility to the plan at t_d are feasible and are retained for further consideration.

4. Select a Course of Action

One of the feasible courses of action is selected to restore feasibility to the plan at the decision point. Fletcher's algorithm uses the maximum ratio of red power destroyed (PD_{ji}) to blue power used (PU_{ij}) as the decision rule [Ref. 5]:

$$PD_{ji}/PU_{ij} \;=\; (SIP^{nc}_{j,t_d} - SIP_{j,t_d})/(SIP^{nc}_{i,t_d} - SIP_{i,t_d}), \qquad (2.8)$$

where SIP^{nc}_{j,t_d} and SIP^{nc}_{i,t_d} are the original power values of the red target and blue asset, respectively, at the decision point if blue unit i were not committed to the course of action. The planning process is thus an optimization of the form: minimize cost, subject to a required level of effectiveness.

Once a feasible course of action is selected, new total power curves are generated and feasibility over the entire planning period is checked. If the overall plan is still infeasible, the process is repeated until overall feasibility is obtained or no assets remain to be committed. In the latter case, or if the assets available can not be committed in such a way as to restore feasibility, the next higher organization is notified. This invokes the micro planning mechanism at that level.

Kilmer theorized the use of other value considerations in this decision process [Ref. 3]. He postulated that

value is related to the importance of an entity in the long term. Two main reasons for considering value are:

- To determine which targets should be prosecuted by a particular asset.
- To determine which asset should prosecute a particular target.

Thus a determination of a unit's value is directly relevant to the selection of a course of action in the planning process.

First, the value of each asset type in the organization is specified as a function of its current ABIP by the use of utility functions. Assuming that each asset type in the organization will remain in the same proportion throughout the battle, this provides the long term importance of the entity, or Usefulness Value (UV):

$$UV(X) = BIP_i \times (1-\exp[G \times X/BIP_i])/(1-\exp[G]) , \quad (2.9)$$

where:

X is SIP_{i,t_p}, and

G is a utility coefficient.

The utility function for a 'risk preferring' decision maker has a $G > 0$, resulting in a convex utility curve (plotting UV vs. SIP). A 'risk neutral' decision maker has a straight line (indifferent) utility curve, and $G = 0$. A $G < 0$ results in a concave utility curve, which is 'risk averse.'

Next, the usefulness value is scaled to account for the availability of the asset and to determine the value, V, of the entity. The scaling factor is the ratio of the desired proportion of the entity type to the existing proportion. The user provides the desired proportion, DP, of each asset type to oppose a specific enemy force for a given mission. Therefore, DP is the desired ratio of the power of the type of entity in question to the power of the entire force:

$$DP_i = (\Sigma BIP(\text{type } i))/(\Sigma BIP(\text{all units})) . \qquad (2.10)$$

The current proportion, CP, of the asset type is:

$$CP_i = (\Sigma ABIP(\text{type } i))/(\Sigma ABIP(\text{all units})) . \qquad (2.11)$$

The value of an entity X of type a is then:

$$V(X(t)) = (DP_a/CP_a) \times UV(X(t)) . \qquad (2.12)$$

Thus value varies directly with the scarceness of the entity type.

The incorporation of Kilmer's value equations in the planning process for the chemical module is described in the next chapter.

III. THE CHEMICAL WARFARE MODULE

A. CONCEPT

1. General

The ALARM chemical warfare module simulates the behavior of a headquarters chemical staff from battalion through Corps level. It is one of the functional modules which interact within the planning process to do the specialized, detailed decision tasks. The functional modules work with each other in much the same way as the functional staff elements in a headquarters organization, coordinating and sharing information. Thus the CW module receives inputs from and provides information to the intelligence, field artillery, air, supply, and transportation modules, as well as the execution model. It relies on solutions from the transportation and time domain networks for planning movements and siting of decontamination assets.

The CW module is logically based on the planning algorithm. It allows the model to incorporate the use of chemical assets in maximizing future power at the point of decision. Since chemical resources are relatively scarce compared to potential need, ALARM's architecture and future state decision making are well suited to their prioritization and scheduling.

The chemical function can be organized into two main areas: (1) retaliatory employment of chemical weapons and (2) chemical defense. Chemical defense can be further divided into its three doctrinal aspects: (1) contamination avoidance, (2) protection, and (3) decontamination.

The overall logic of a basic CW module is depicted in the flow chart in Figure 3-1. Based on the logical flow, a FORTRAN computer program demonstrates the application of the CW module (Appendix B).

2. Program Development

The application program is designed with interactive data input and output to form the basis for development of a training or planning aid for commanders and staffs in the field. In the context of ALARM, the terminal prompts and displays represent calls to other modules requesting or providing information.

The program is limited to the types of units used in the demonstration scenario amd its design is such that the database can be readily broadened for more general application. Each application (iteration) simulates operation of the planning algorithm at a particular organizational level (i.e., that level's subordinate units are the inputs for the problem).

This program extends previous applications of the GVS in several ways. It is more generalized than the specific-case programs previously done; many-on-many

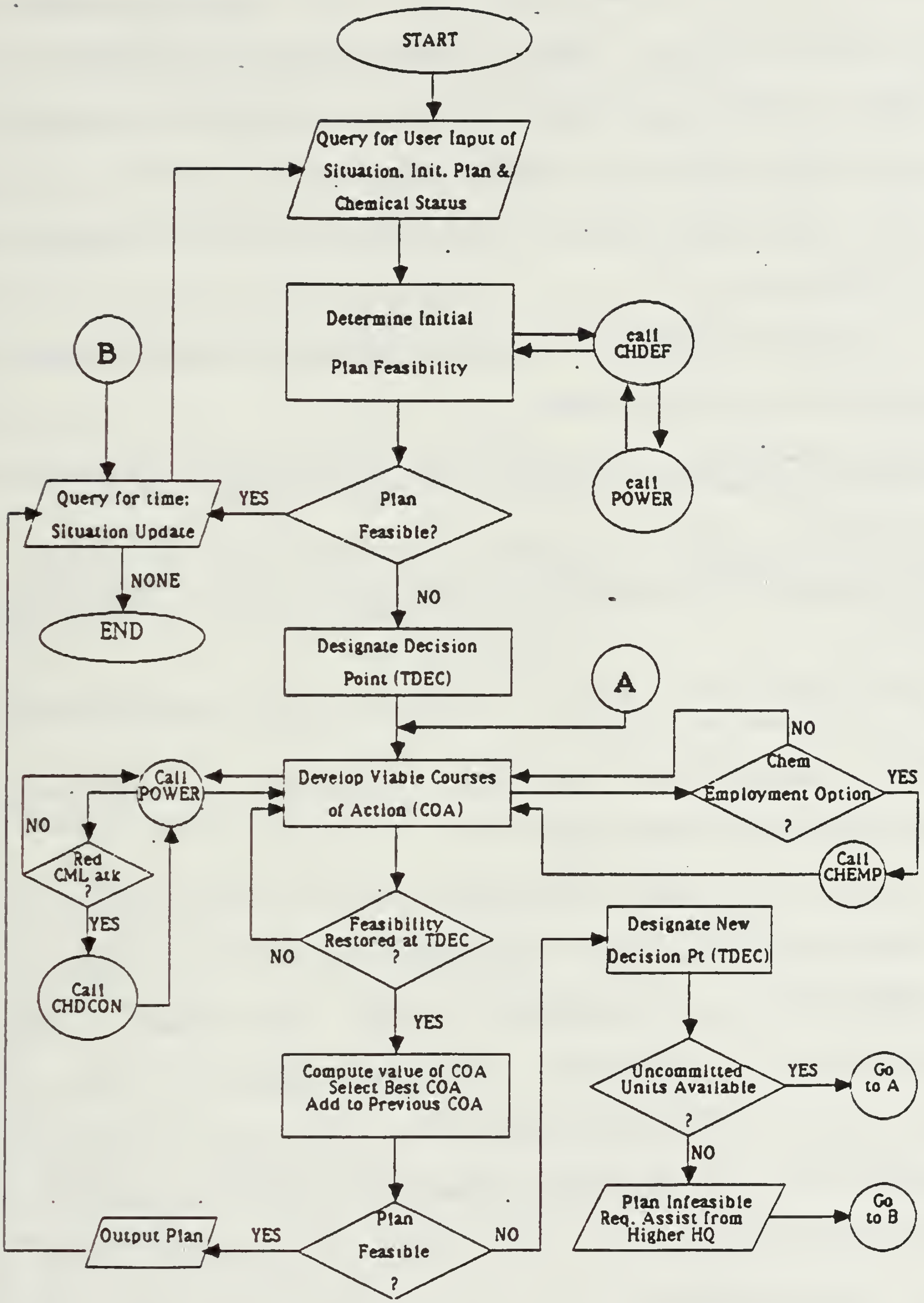

Figure 3-1 Logic Flow Chemical Warfare Model

engagements can be modelled, rather than one-on-one; and Kilmer's value considerations are added to the course of action decision rule. Where appropriate, the program uses the ALARM convention of functionalizing physical parameters and computing updated values as needed. This is more efficient than maintaining large and unwieldy data bases for table-look-ups.

Mission profiles for the blue uncommitted units in the program are as follows:

- Field artillery: 1/2-hour fire mission followed by 1/2-hour displacement, to avoid counter-battery fire.
- Attack helicopter: actual movement time to target, 1 hour on station, movement time to return to the Forward Area Refuel and Rearm Point (FARRP), and 1/2-hour FARRP time.
- Armor battalion: movement time to target, engagement to end of planning period.

Thus the artillery and helicopter units can be committed to multiple courses of action.

The main program contains most of the interactive input and output controls. Following input of the situation (the original plan), subroutine CHDEF is called. CHDEF establishes the appropriate Mission Oriented Protective Posture (MOPP) in chemical protective clothing and equipment by trading off the chemical threat against the ability to perform the mission. In so doing, subroutine POWER is called, which computes the power curves for both sides, determines the difference between them, and determines the

plan's feasibility and designates the decision point if the plan is infeasible.

Returning control to the main program, if the plan is infeasible, courses of action are generated to restore feasibility. Each uncommitted blue unit is paired against each red unit in turn, beginning in each time step from the beginning of the planning period to the decision point. If red has previously employed chemical weapons and blue has subsequently been granted chemical employment authority, each field artillery unit is cycled through the course of action generation twice. On the first pass, conventional fire missions are planned. On the second, subroutine CHEMP is called to plan the same missions as chemical strikes and predict the effect on the target.

Viability of each course of action is checked considering range, previous commitment, and sufficient time before the decision point. For viable missions, subroutine POWER is again called to determine whether adding the course of action to the plan restores feasibility at the decision point. If so, the value of the course of action is determined and the ratio of red power destroyed to blue power used is computed with the modifications discussed in the next section. The course of action with the highest ratio is added to the plan.

If a unit or units have been contaminated by red chemical attacks, subroutine POWER calls subroutine CHDCON

to determine the effect on that unit's power curve of withdrawing to the decontamination site and that effect is incorporated in the course of action determination.

This process is repeated until feasibility is restored throughout the planning period or no uncommitted units are available. In either case, results are reported and a prompt for a situation update is provided. The user can then advance the scenario time and re-run the program with an updated situation or terminate the program.

B. CHEMICAL WEAPONS EMPLOYMENT

1. Concept

The CW module includes the employment of chemical weapons by blue field artillery as one option in the development of courses of action to restore feasibility to the plan. In practice, chemical target planning begins with identification and location of a potential target by the intelligence staff. Using weather information and known (and imputed) target information such as size, protection, equipment available, and activity, and the desired effects of the chemical attack, the number of rounds of the type of chemical agent required for the mission is obtained from targeting tables. Proximity of friendly troops or towns is included as a planning factor. A parallel process is followed in the CW module.

Target and weather information is received from the intelligence module. Following preparation of feasible

courses of action by a field artillery unit (by pairing the unit with each red target in each time step) using conventional weapons, a chemical employment submodule (subroutine CHEMP in the application program) is called and the process is repeated with the same artillery unit using chemical weapons. Based on perceived target parameters from the intelligence module, the submodule determines the number of chemical rounds required and the predicted effects on the target. These effects are in terms of casualties and operational degradation due to the encumbrance of protective clothing and equipment and having to operate in a protected configuration. These effects are applied as the attrition coefficient in the SIP calculations for the target unit. The results of these courses of action are then included in the overall selection of a course of action to restore feasibility at the decision point.

2. Value

Fletcher's decision criterion, red power destroyed to blue power used (PD/PU), would treat the conventional and chemical fire missions the same. Since the chemical attacks generally have a greater effect on the target, these missions would almost always be selected over conventional ones by this criterion. This approach does not take into account the different natures of the two types of missions accomplished by the same entity nor the relative scarceness of chemical munitions and the requirement to employ a

comparatively larger number of them to reach a threshold of effect. Thus the true relative values are not included in the course of action determination, nor are the possibilities of preserving the chemical weapon allocation for higher priority targets. Combining Kilmer's value concept with Fletcher's decision rule offers an approach to address this problem. Equations 2.8-2.12 are designed to compare the values of different entities performing particular tasks. Chemical weapons are reflected as a mission of a delivery entity. The approach taken here is to add to these equations factors expressing the relative values of the various missions of an entity. Kilmer's value is the long-term usefulness value (UV) of an entity, scaled by its scarceness: the ratio of its desired proportion of power in the force to its current proportion of power (DP/CP), as given by Equation 2.12:

$$V = (DP/CP) \times UV. \qquad (2.12)$$

Usefulness value is the utility curve for the entity:

$$UV = BIP\ (1 - \exp\{G \times SIP/BIP\})/(1 - \exp\{G\}). \qquad (2.9)$$

The value of the utility coefficient, G, used in the application program is G = -3, reflecting a risk averse

decision maker. This means that the decision maker prefers a certain outcome over the chance of even greater gain, a cautious approach. The validity of G values is subject to further verification during the development of ALARM.

A factor is then added to the value equation (Eqn 2.12) to express the scarceness of a mission capability. In this application the ratio of the desired proportion of chemical munitions (among all munitions) for a particular entity to the actual proportion is used (DP_{chem}/CP_{chem}). This ratio is added to the entity scarceness factor in the value equation for chemical missions:

$$V = (DP/CP + DP_{chem}/CP_{chem}) \times UV. \qquad (3.1)$$

Since both of these factors can take values greater than 1, reflecting relative scarceness, they are added rather than multiplied to prevent a large value in either factor from having a disproportionate effect. For non-chemical courses of action, the complements of the proportions are used in the ratio:

$$(1 - DP_{chem})/(1 - CP_{chem}).$$

For consistency of comparisons in the computer application, a mission capability scarceness factor of 1 was added for non-field artillery units, reflecting a balance between

mission-required resources and availability. In a full implementation of the model, any entity could add a similar mission-specific value if needed.

This expanded value expression is then incorporated in the decision rule as the ratio of red power destroyed to blue power used times the value of that power: PD/(PU x V). Value (V) increases as an entity becomes scarcer. Therefore, scarceness reduces this ratio. Since the course of action with the maximum PD/(PU x V) ratio is selected, inclusion of the value factor can have the effect of saving a scarce asset or mission capability for a higher priority target or one with a greater payoff in terms of power destroyed. Additionally, as chemical rounds are used and their proportion in the overall stockpile is reduced, the value of a chemical mission increases. This decreases the likelihood of a chemical course of action being selected for a given target in order to conserve the resource.

3. Program Development

For simplicity a limited chemical employment capability is portrayed as shown in Table 3-1. Each of the factors in Table 3-1 can be expanded by incorporating the added parameters in data matrices and in the functional determinations.

One problem currently experienced in modelling blue chemical employment is that existing target planning manuals are out of date. New versions are being prepared, but

TABLE 3-1

CHEMICAL EMPLOYMENT CAPABILITY IN ALARM CW MODULE

Delivery system	203 mm howitzer, battalion fire
Chemical agent	Persistent nerve agent, VX
Effects	30% casualties Average movement speed x 0.5
Target parameters	Size--choice of 2: Battalion, Regiment

current, accurate planning factors are not available. For this project, figures were obtained from a draft manual and arbitrarily adjusted to avoid security classification.

Partly as a result of this lack of data, weather and preclusion of civilian or friendly casualties are not included in the program. Weather effects are one set of factors included in targeting data tables and function solutions being developed. Weather information is used with information from the Cartesian space network giving the distances and directions to towns and friendly troop concentrations, allowing the consideration of precluding civilian and friendly casualties.

The chemical effects curves are essentially flat for about 16 hours after the attack, followed by gradual recovery. Since this is about the length of a scenario run by the program, only this constant effect is modelled. To incorporate the recovery curve in a longer scenario is a matter of adding an additional time-dependent factor to the

effects function. The chemical employment effects are a combination of lethal and non-lethal casualties, and heat stress and operational degradation caused by protective clothing and operating in a "buttoned-up" configuration. Effects are expressed as percent effectiveness and are applied as the attrition coefficient in the situational inherent power (SIP) equations (Equations 2.5 and 2.6). The targeting procedure is to enter the table with the desired percent casualties and target parameters to determine the number of rounds to fire. Then the effects tables or functions are entered with the number of rounds, giving the predicted percent effectiveness of which the target unit will be capable. For the program, 30 percent casualties implies 57.5% effectiveness. The attrition coefficient is applied as an exponential function of time in the SIP equations,

$$(\exp\{-ATT \times (t - t_{attack})\}),$$

and is therefore an hourly rate of power decline. The field artillery mission profile in the program uses a 0.5 hour attack duration. Therefore the effectiveness percentage is applied in the SIP equation as:

$$ATT = (-\ln 0.575)/0.5. \qquad (3.2)$$

Thus, in a 1/2-hour field artillery chemical fire mission, the target unit's power is reduced by a factor of 0.575. The target's power remains at this level due to the flatness of the chemical effects curve, subject to continuing usage of resources and subsequent attacks.

In addition to the effectiveness factor, the target unit's speed of movement is reduced by half, reflecting the difficulty of operating in a fully protected posture. This reduces the slope of the target entity's power increase function as it approaches its mission location and delays its arrival. Thus a chemical attack both delays and destroys the target's power, tending to shift the overall red power curve to the right and effectively restoring feasibility at the decision point.

C. CHEMICAL DEFENSE

1. Concept

Chemical defense is characterized by centralized planning and decentralized execution. Execution factors, which are functions of doctrine, equipment, organization and training, are represented in the execution model with guidance from and feedback to the ALARM planning model. For the CW planning module, the approach is to decompose chemical defense into its three doctrinal aspects: contamination avoidance, protection, and decontamination. As described below, there is some interdependence and interaction among these parts.

2. Contamination Avoidance

Contamination avoidance is the most basic aspect of chemical defense. If a unit can avoid becoming contaminated in the first place, then the casualties, the first aid and medical treatment problems, the operational degradation due to the encumbrance of protective clothing and equipment, and the need to divert assets for decontamination are all averted. Contamination avoidance is accomplished largely by application of the Nuclear, Biological, and Chemical (NBC) Warning and Reporting System, NBC reconnaissance, and active and passive monitoring using chemical agent detectors and alarms. NBC reconnaissance is currently receiving much attention for the further development of doctrine and force structure. Because of its uncertain shape, it is not included in this application. Reconnaissance planning can be incorporated into the CW module when its objectives and planning requirements are more settled. The other two aspects, the warning and reporting system and monitoring, are conducted as prescribed by doctrine and in the case of monitoring, at the lowest organizational levels. Therefore they should be incorporated in the execution model and need not be reflected in the planning model.

3. Protection

Protection from chemical agents is applied both individually and collectively. Collective protection depends on the availability of equipment and facilities with

field expedient approaches encouraged. Little, if any, structured planning at battalion to corps levels is done for collective protection. Individual protection is achieved through the application of Mission Oriented Protective Posture (MOPP) as described in Appendix A. MOPP is intended to be a flexible system of standardized protection levels applied at the lowest feasible command level. However, it is amenable to the requirement of specific minimum protection levels by higher level commanders based on a better perception of the threat. MOPP seeks to trade off the risk of casualties from a chemical attack with the operational degradation and heat casualties caused by encapsulation in protective clothing. This is the process modelled by the CW module. An initial MOPP level is set for each unit based on the chemical threat perceived by the intelligence module. The resultant operational degradation is applied by reducing each entity's state and speed of movement appropriately. Then the initial plan feasibility check is made. If the plan is infeasible, MOPP levels are reduced and feasibility rechecked, iteratively, until feasibility is achieved or a prescribed minimum MOPP level is reached. If the plan is still infeasible, then the planning process is initiated to restore feasibility. Units which are under chemical attack or are contaminated are placed in MOPP-4, the highest level, and remain so until decontaminated (see Appendix A). MOPP levels are reviewed

periodically and adjusted as required by a changing threat or unacceptable loss of operational capability.

4. Decontamination

Should contamination avoidance fail and protection succeed, personnel and equipment must be decontaminated. Hasty decontamination by individuals and crews removes minor contamination and reduces the hazard from more copious contamination. Deliberate decontamination supported by chemical companies removes essentially all chemical agent or at least reduces the danger to a level that allows the unit to be restored to its previous state, unencumbered by MOPP.

Chemical companies are in short supply relative to the possibility of many units requiring their services in a short period of time. Deliberate decontamination is time consuming, requires a great deal of water, and can pose security problems because it concentrates the unit in a static, difficult to defend posture.

The planning task is to position the decontamination support assets in the most advantageous location and allocate their efforts in a way that returns the most combat power to action in the most timely way. The use of future state decision making in ALARM lends itself to this task. The decontamination sites are located by the Cartesian space network solver. Decontamination support is scheduled by incorporating the contaminated units into the course of action generation in the planning algorithm. Thus the

contribution to the force's total power of decontaminating a particular unit at a particular time is factored into the selection of a plan.

5. Program Development

In the application program, subroutine CHDEF performs the protection planning function described above. Another aspect of CW where quantified data are lacking is performance degradation due to MOPP. Data to support a unit's state and speed reduction because of MOPP were derived from a preliminary effort in this area [Ref. 8]. This was done by averaging the percent effectiveness in MOPP of several tasks measured in the study that are representative of the types of tasks units in the program scenario would be doing. Only one temperature range was modelled ($10^{\circ}C$). Again, this aspect and others such as variations of workload among types of units and missions can easily be expanded by incorporating additional data in a matrix or an appropriate function as data become available from studies currently under way. The MOPP degradation factors used in the program are listed in Table 3-2.

Red chemical weapon effects on blue units were derived from data used in the Vector-in-Commander (VIC) corps-level model. This model has been adopted by the Army's Training and Doctrine Command for corps-level analyses. Units under persistent agent attack or previously contaminated are automatically placed in full MOPP level 4

TABLE 3-2

OPERATIONAL DEGRADATION FACTORS DUE TO MISSION ORIENTED PROTECTIVE POSTURE (MOPP)

MOPP level	State	Speed
1	1	1
2	0.95	1
3	0.75	0.75
4	0.5	0.5

protection and remain so until decontaminated. Thus they are already at 50 percent effectiveness. Additionally, 10 percent casualties are assessed immediately after the chemical attack, with a continuous exponential loss from delayed casualties. It is assumed that a total of 30 percent casualties will occur within 24 hours. The casualty factor as a function of time is thus derived from: $0.9 \exp(-C \times 24) = 0.7$, so $C = 0.01047$. This factor is included in a chemical effect factor multiplied by a contaminated unit's SIP to determine the effect of the chemical attack at the time the SIP is computed. This factor is a recomputation of the unit's state function, incorporating chemical attrition, MOPP degradation, and dividing out the unit's original state value:

$$\text{CHEM EFF} = (\text{SQRT}\{0.9\exp(-C(t-t_C)) \times f(\text{STATE})\}) \times 0.5/f(\text{STATE}) \qquad (3.2)$$

where:

t_c is the time of the chemical attack, and

f(STATE) is the state function discussed in Chapter II (the square root of the product of the percentages of equipment and personnel on hand).

During the course of action generation, it is assumed that a contaminated unit cannot withdraw from its position to move to the decontamination site until another unit is committed against the red unit or units it opposes. Thus contaminated units are moved to decontamination only in courses of action wherein the uncommitted blue unit is targeted against the contaminated unit's target unit. The move to the decontamination site commences when the uncommitted blue unit engages the target.

Two data structures are used to account for contaminated units. The unit identifiers are placed in a stack by subroutine CHDEF, and at the decontamination site they are placed in a queue, so that one unit may not begin decontamination until the unit ahead of it is finished. When it is decontaminated, a unit's identifier is removed from the stack.

As a unit moves to the decontamination site, its power is discounted, since it is moving away from the location where its mission is performed. During decontamination, assumed to last 4 hours, its power increases to a new ABIP based on the distance from the

decontamination site to the unit's mission location and the state resulting from the chemical casualties to that time, but without MOPP degradation. At the end of decontamination, the unit reverts to MOPP level 1 and is considered an uncommitted unit available to be included in course of action determinations. The power curve of a unit undergoing decontamination is computed by subroutine CHDCON and passed back to subroutine POWER for inclusion in the blue force total power curve. A factor expressing the value of decontamination is included in the course of action decision rule. This factor is the ratio of the contaminated unit's SIP at the decision point following decontamination to its SIP at the decision point if it were not decontaminated. Uncontaminated units have a decontamination value of 1. The decontamination value is bounded by 0.5 and 1.5 to prevent it from having an overwhelming effect on the decision ratio.

The FORTRAN program at Appendix B implements the chemical module described in this chapter. The program was run with a combat scenario to demonstrate its application. The scenario and the results of the demonstration run are described in the next chapter.

IV. APPLICATION OF THE MODEL

A. BASIC SCENARIO

The chemical warfare module application program was run using a division-level combat scenario. The scenario consists of a basic situation and three updates advancing the planning time and developing the situation.

The scenario concerns a blue armor division in the Fulda Gap region of West Germany. The division's mission is to defend in sector, preventing attacking red forces from crossing the initial division rear boundary for 48 hours. This demonstration covers the first 24 hours of the mission. The division's three brigades are committed in defensive sectors against attacking red first echelon motorized rifle divisions (MRD). One red MRD is attacking each blue brigade. In addition to the brigades, the blue division has three uncommitted units: the general support field artillery battalion, an attack helicopter company, and an armor battalion as the division reserve.

The input parameters required by the program are listed in Table 4-1. STATE is the value of the state function, f(STATE), the square root of the product of the percentages of personnel and equipment on hand at the beginning of the scenario. DIST is the initial distance of the unit from its battle position. Desired proportion is the fraction of that

TABLE 4-1

PROGRAM DEMONSTRATION--BASIC SITUATION

TIME = 0 HOURS

ID NO	TYPE UNIT	BIP	STATE	DIST	SPEED	DESIRED PROP.	CHEM THRT	OPP UNIT	ATT. RED	COEFF. BLUE
BLUE										
1	ARM BDE	4800	1	20	10	.55	3	1	.1	.05
2	ARM BDE	4800	1	20	10	.55	3	2	.1	.05
3	ARM BDE	4800	1	20	10	.55	3	3	.1	.05
4	FA BN	1800	1	20	10	.2	3	NC*	.1	.02
5	HELO CO	800	1	20	40	.15	3	NC	.2	.1
6	ARM BN	1000	1	20	10	.1	3	NC	.1	.05
RED										
1	MRD	14000	.8	20	10	-	-	1	-	-
2	MRD	14000	.8	20	10	-	-	2	-	-
3	MRD	14000	.8	20	10	-	-	3	-	-

* - Not committed initially

type of unit's power in the total force that the decision maker would prefer to have available. CHEM THRT is keyed to a list of qualitative chemical threat values from which the user is asked to select. These data are entered interactively by the user at the terminal in response to screen prompts. Information for each blue entity in turn is entered, followed by each red entity and some general information about the scenario. For brevity the entries for only the first blue and red entities are shown in Figure

4-1. The key for the Chemical Threat ("CHEM THRT") entry is shown in Figure 4-1. The initial situation always begins at planning time T = 0.

For blue field artillery units, the program also asks for the information shown in Figure 4-2 in order to compute the mission capability value factors described in Chapter III.

The program first determines the appropriate Mission Oriented Protective Posture (MOPP) levels and checks initial plan feasibility (Figure 4-3).

As shown in Figure 4-3, the initial situation proves to be feasible. This can be seen by examining the red and blue total power curves in Figure 4-4. The blue plan is feasible if the difference between the power curves is greater than the feasibility threshold throughout the planning period. The feasibility threshold for this demonstration is 0.

At this point the division plan is passed to the brigade planners for preparation of their own feasible plans.

B. FIRST UPDATE

The program next prompts for an update time or the program can be terminated (Figure 4-5).

At time T = 2 hours, the intelligence module detects a second echelon red tank division entering the blue division's area of interest at a distance of 120 kilometers. At this point, blue has no specific indicators of the red

```
EXECUTION BEGINS. . .
To terminate program during data input, enter 999 in
response to any prompt for data.

At time T = 0

Enter the number of blue entities (units):
?
6
For each Blue entity, enter the information requested (units
under chemical attack or contaminated should be entered
last).

  Blue entity (ID no.)          1 :
       Unit Type (enter no. 1-6)
            1 - Armor Div
            2 - Armor Bde
            3 - FA Bn (203-mm SP)
            4 - Atk Helo Co
            5 - Armor Bn
?
2
       Mission (enter no. 1-2)
            1 - Attack
            2 - Defend
?
2
       Basic inherent power (BIP) in STAPOWS
?
4800
       State, at T = 0
            (SQRT(% personnel x % equipment))
?
1
       Distance from assigned battle position (km)
?
20
       Average speed of travel (when moving)(km/hr)
?
10
       Desired proportional power of this type
       unit in Blue force, for this mission
?
.55
```

Figure 4-1 Program Data Inputs

```
        Chemical threat (enter no. 1-6)
             1 - None
             2 - Unlikely
             3 - Moderate
             4 - High
             5 - Immediate
             6 - Under chemical attack/
                  in contaminated area
?
3
        Number of Red entities opposing this unit
             (0 = Not committed)
?
1
        Red entities opposing this unit (ID no.)
             (Enter one at a time)
?
1
        Attrition coefficient for BLUE unit                 1
         on RED unit             1
?
.1
        Attrition coefficient for RED unit                  1
         on BLUE unit            1
?
.05

Enter the number of Red entities (units):
?
3
For each Red entity, enter the information requested

        Red entity (ID no.)            1 :
             Unit type (enter no. 1-4)
                  1 - Tk Div
                  2 - MR Div
                  3 - Tk Rgt
                  4 - MR Rgt
?
2

             Mission (enter no. 1-2)
                  1 - Attack
                  2 - Defend
?
1
             Basic inherent power (BIP) in STAPOWS
?
14000
```

Figure 4-1 (CONTINUED)

```
              State, at T = 0
                   (SQRT(% personnel x % equipment))
?
.8
              Distance from battle position (km)
?
20
              Average speed of travel (when moving)(km/hr)
?
10
Has Red employed chemical weapons (Y/N)?
y
Does Blue have chemical employment
     authority (Y/N)?
y
Enter mission duration (no. hours from T=0)
?
24
```

Figure 4-1 (CONTINUED)

```
              Daily allocation of chemical artillery rounds
?
500
              Daily allocation of artillery rounds
               (all types)
?
10000
              Desired daily allocation of chemical
               artillery rounds
?
1000
```

Figure 4.2 Additional Information Required for Field Artillery

Recommended MOPP:

BLUE unit	1 , MOPP	1
BLUE unit	2 , MOPP	1
BLUE unit	3 , MOPP	1
BLUE unit	4 , MOPP	1
BLUE unit	5 , MOPP	1
BLUE unit	6 , MOPP	1

Situation feasible at this time.

Figure 4-3 Result of Basic Situation

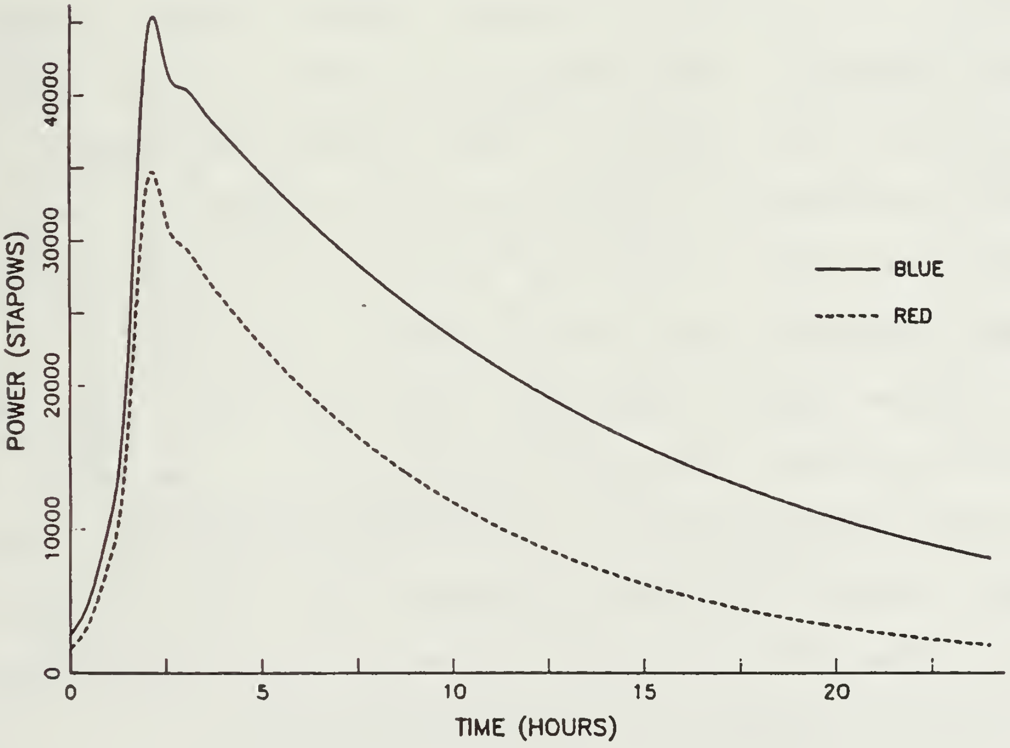

Figure 4-4 Power Curves, Basic Situation

```
 Enter time of update (hrs since T = 0)
   (if none, enter 999 to terminate program)
?
2

 At time T =    2.00000000

Enter the number of blue entities (units):
?
6
```

Figure 4-5 First Update

tank division's plan of attack. Therefore, the red division's power is applied uniformly across the blue division's sector (i.e., one-third of the red division's power is applied against each blue brigade). This is essentially the LaPlace principle of choice for a decision under risk: expectation of equally likely futures. [Ref. 9] The program again asks for input of the basic information for all entities. This allows for changes in the force structures or allows the user to shift to another organizational level as will be seen in the third update. The input parameters are now as shown in Table 4-2.

The program again determines the best MOPP level for each unit and checks feasibility (Figure 4-6). The entry of the red tank division makes the blue plan infeasible. The new power curves are shown in Figure 4-7. The decision point is at time T = 13.5 (when the power curves cross since the feasibility threshold is a difference of 0).

TABLE 4-2

PROGRAM DEMONSTRATION--FIRST UPDATE

TIME = 2 HOURS

ID NO	TYPE UNIT	BIP	STATE	DIST	SPEED	DESIRED PROP.	CHEM THRT	OPP UNIT	ATT. RED	COEFF. BLUE
BLUE										
1	ARM BDE	4800	1	0	10	.55	3	1 4	.1 .1	.05 .05
2	ARM BDE	4800	1	0	10	.55	3	2 5	.1 .1	.05 .05
3	ARM BDE	4800	1	0	10	.55	3	3 6	.1 .1	.05 .05
4	FA BN	1800	1	0	10	.2	3	NC*	.1	.02
5	HELO CO	800	1	20	40	.15	3	NC	.2	.1
6	ARM BN	1000	1	10	10	.1	3	NC	.1	.05
RED										
1	MRD	14000	.8	0	10	-	-	1	-	-
2	MRD	14000	.8	0	10	-	-	2	-	-
3	MRD	14000	.8	0	10	-	-	3	-	-
4	TK DIV-	5000	1	120	10	-	-	1	-	-
5	TK DIV-	5000	1	120	10	-	-	2	-	-
6	TK DIV-	5000	1	120	10	-	-	3	-	-

* - Not committed initially

Recommended MOPP:

BLUE unit	1 ,	MOPP	1
BLUE unit	2 ,	MOPP	1
BLUE unit	3 ,	MOPP	1
BLUE unit	4 ,	MOPP	1
BLUE unit	5 ,	MOPP	1
BLUE unit	6 ,	MOPP	1

Situation infeasible. Preparing feasible plan.

Figure 4-6 Result of First Update

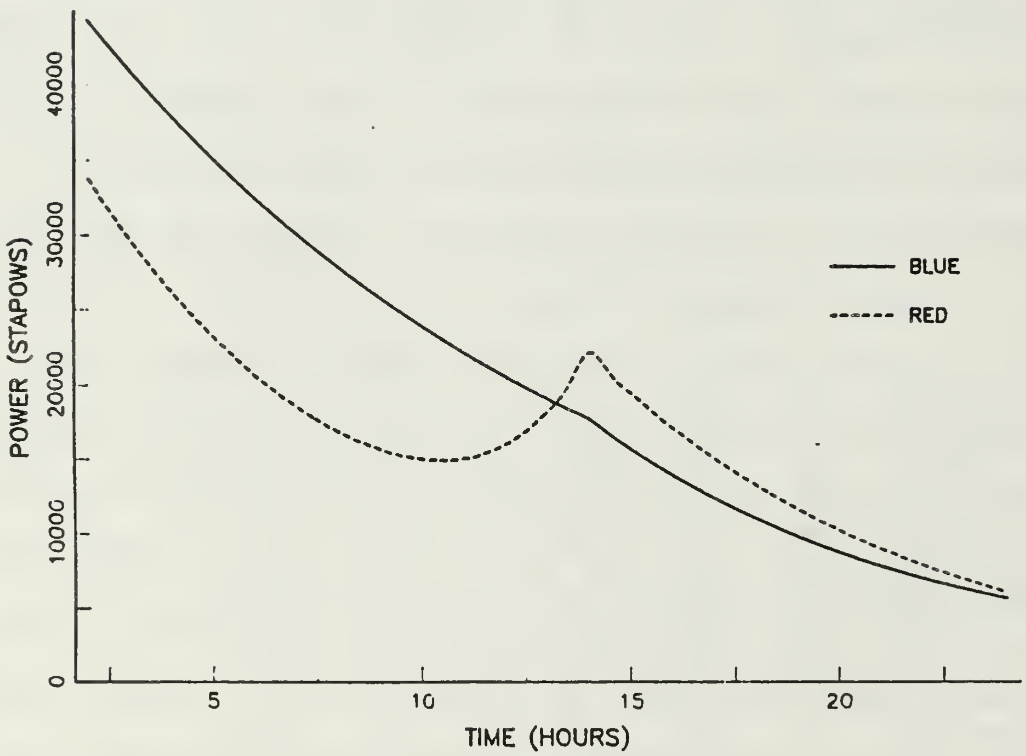

Figure 4-7 Power Curves, First Update

The program now begins to search for a feasible plan. It prompts for the attrition coefficients for each uncommitted blue unit versus each red unit when it first

pairs those particular units. The attrition matrix is thus built interactively but entries are required only for pairings that are tested, and only the first time each pair is tried. This scheme reduces the overall data input load for the user. Upon restoration of feasibility, the plan is displayed (Figure 4-8).

```
Feasibility restored by plan:
 TIME      BLUE UNIT  ON    RED UNIT      CHEM OR CONV
 12.0          4               4               CHEM
```

Figure 4-8 Feasible Plan--First Update

As shown in Figure 4-8, feasibility is restored by blue unit 4, the field artillery battalion, firing a chemical mission against red unit 4, one of the partial tank divisions, at time T = 12. The restoration of feasibility is shown by the new power curves at Figure 4-9. Given the speeds and distances involved, the mission is to be fired at maximum range, when the red division is still 20 kilometers from engaging the blue division. The ALARM planning algorithm has thus determined that interdicting an approaching force is the best course of action, a key concept of AirLand Battle. It can be observed that firing this mission against any of the partial red tank divisions gives the same results, since the same parameters are used. When several feasible courses of action have the same value the program reports the first one found.

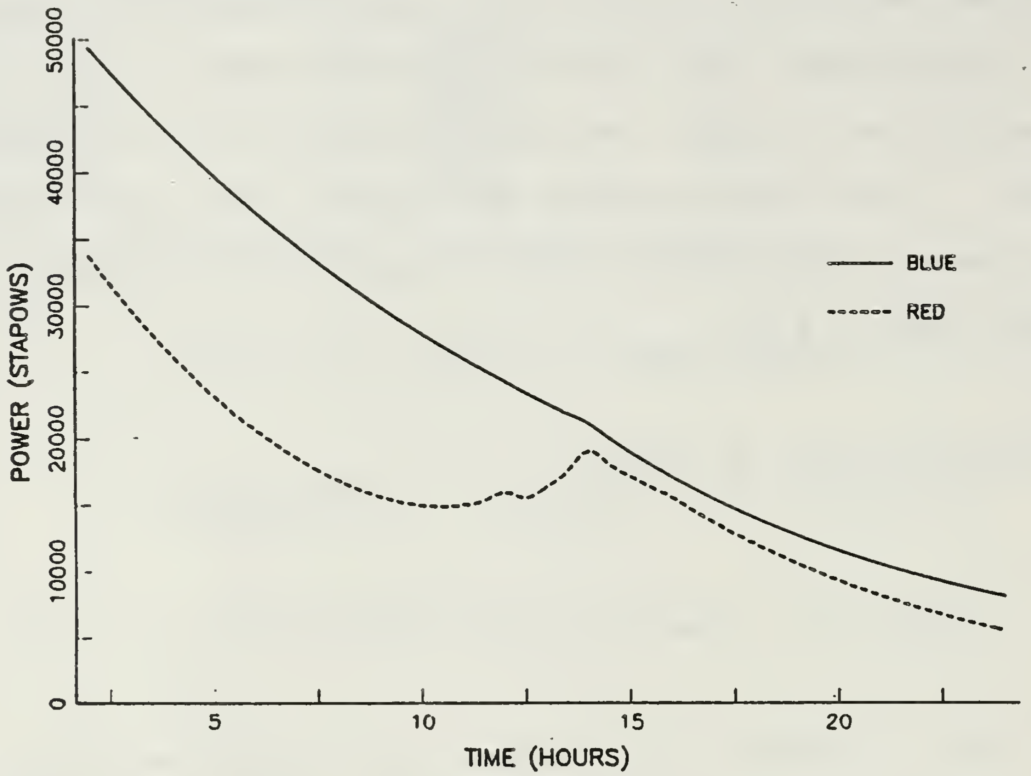

Figure 4-9 Power Curves, First Update Plan Restoring Feasibility

To review how this course of action is selected, the decision rule is to choose the course of action with the greatest value of the ratio of red power destroyed to blue power used times the value of blue power, PD/(PU x V) (see Chapter III). The computation of this quantity is outlined below, comparing it to a possible alternative course of action that was not selected. The equations are derived from the general equations described in Chapters II and III, applied here in the same specific ways that the program does.

The power of red unit 4 at the decision point, $T = 13.5$, if it were not attacked is derived from equation 2.5, since it does not arrive at its battle position until $T = 14$ hours:

$$SIP_{R4(nc),13.5} = ABIP_{R4} \times \exp(D_{R4} \times (13.5-2)).$$

Equation 2.1 defines adjusted basic inherent power (ABIP) as:

$$ABIP = BIP \times (K/DIST) \times f(STATE),$$

where:

K is the mission factor,

DIST is the original distance from the battle position, and

f(STATE) is the state function, here the square root of the product of the percentages of personnel and equipment on hand.

Therefore:

$$ABIP_{R4} = 5000 \times 1/120 \times 1 = 41.6667.$$

The computational form of Equation 2.3 for the power growth exponent, D:

$$D = (\ln(DIST))/(t_a - t_p) ,$$

gives:

$$D_{R4} = (\ln(120))/(14 - 2) = 0.3990.$$

Therefore the power of the target unit at the decision point if not attacked is:

$$SIP_{R4(nc),13.5} = 41.6667 \times \exp(0.3990 \times 11.5) = 4096.$$

Following the chemical attack at T = 12.5, the power equation is derived from Equation 2.5 as:

$$SIP_{R4,12.5} = 2251 \times \exp((D_{R4} - ATT)x(0.5)),$$

where:

$$ATT = (-\ln(0.575))/0.5 = 1.1068. \qquad (3.2)$$

Therefore:

$$SIP_{R4,12.5} = 2251 \times \exp((0.3990 - 1.1068)x0.5)) = 1580,$$

and by T = 13.5:

$$SIP_{R4,13.5} = 1580 \times \exp(D_{R4}x(13.5 - 12.5)) = 1929.$$

Therefore the red power destroyed is:

$$PD = 4096 - 1929 = 2167.$$

Blue unit 4 is in its battle position consuming resources since T = 2, so its power at T = 13.5, if it does not fire this mission is derived from Equation 2.5 as:

$$SIP_{B4,13.5} = SIP_{B4,ta} \times \exp(-U_{B4} \times (13.5 - 2)).$$

Since:

$$SIP_{B4,ta} = BIP_{B4} \times K_{B4} \times f(STATE_{B4})$$
$$= 1800 \times 3 \times 1 = 5400,$$

and U_{B4} is assumed to be 0.03:

$$SIP_{B4,13.5} = 5400 \times \exp(-0.03 \times 11.5) = 3824.$$

Before firing the mission at T = 12:

$$SIP_{B4,12} = 5400 \times \exp(-0.03 \times (12 - 2)) = 4000.$$

Following the mission at T = 12.5, blue unit 4's power is:

$$SIP_{B4,12.5} = 4000 \times \exp((-0.03 - 0.02) \times (0.5)) = 3902.$$

At the decision point, T = 13.5:

$$SIP_{B4,13.5} = 3902 \times \exp(-0.03 \times (13.5 - 12.5)) = 3786.$$

The blue power used is:

$$PU = 3824 - 3786 = 38.$$

The usefulness value, UV, of blue unit 4 is:

$$UV = BIP \times (1 - \exp(G \times SIP/BIP))/(1 - \exp(G)), \quad (2.9)$$

so with G = -3:

$$UV_{B4} = 1800 \times (1 - \exp(-3 \times 3786/1800))/(1 - \exp(-3))$$
$$= 1891.$$

The value of blue unit 4 is:

$$V = (DP/CP + DP_{chem}/CP_{chem}) \times UV, \qquad (3.1)$$

where

$$CP = ABIP_{B4}/ABIP_{all} = 270/2700 = 0.1.$$

Therefore:

$$V_{B4} = (0.2/0.1 + (1000/10{,}000)/(500/10{,}000)) \times 1891$$
$$= 7563.$$

In the program, V is scaled by 1/10,000 to avoid precision problems, so the final value us:

$$V_{B4} = 0.7563.$$

The decision ratio for this course of action is:

$$RATIO = 2167/(38 \times 0.7563) = 75.$$

For comparison, corresponding figures for an attack helicopter mission beginning at T = 12 and ending at T = 13,

since the mission profile for the helicopter company includes one hour on station, are:

$$PD = 743$$

$$PU = 229$$

$$V_{B5} = 0.3682$$

and

$$RATIO = 743/(229 \times 0.3682) = 8.8.$$

Therefore even though the value for the chemical artillery strike is greater, the differences in red power destroyed and blue power lost cause the chemical mission to be preferred. The program determines that this course of action is in fact preferable to all others, given the parameters used.

C. SECOND UPDATE

The program again prompts for an update time. At time T = 6 hours (still 8 hours from the arrival of the red tank division at the forward edge of the battle area), the intelligence module reports indicators showing that the red tank division will attack through the 1st Brigade sector to create a penetration. Since the other two brigades are facing their original opponents, their initial plans remain feasible. The division now focuses its planning on the 1st Brigade. The input parameters for this iteration are listed in Table 4-3.

TABLE 4-3

PROGRAM DEMONSTRATION--SECOND UPDATE

TIME = 6 HOURS

ID NO	TYPE UNIT	BIP	STATE	DIST	SPEED	DESIRED PROP.	CHEM THRT	OPP UNIT	ATT. RED	COEFF. BLUE
BLUE										
1	ARM BDE	4800	1	0	10	.55	3	1	.1	.05
								2	.1	.05
2	FA BN	1800	1	0	10	.2	3	NC*	.1	.02
3	HELO CO	800	1	20	40	.15	3	NC	.2	.1
4	ARM BN	1000	1	10	10	.1	3	NC	.1	.05
RED										
1	MRD	14000	.8	0	10	-	-	1	-	-
2	TK DIV	15000	1	80	10	-	-	1	-	-

* - Not committed initially

Again, MOPP levels and feasibility are determined (Figure 4-10).

```
   Recommended MOPP:
BLUE unit            1 , MOPP          1
BLUE unit            2 , MOPP          1
BLUE unit            3 , MOPP          1
BLUE unit            4 , MOPP          1
 Situation infeasible.  Preparing feasible plan.
```

Figure 4-10 Result of Second Update

Infeasibility occurs at time T = 11.5 hours, as seen in the power curves (Figure 4-11). This is 2 hours earlier than in the first update, because red power is more concentrated and the imbalance is therefore greater. Attrition coefficients are entered as requested, and the plan restoring feasibility is reported out (Figure 4-12).

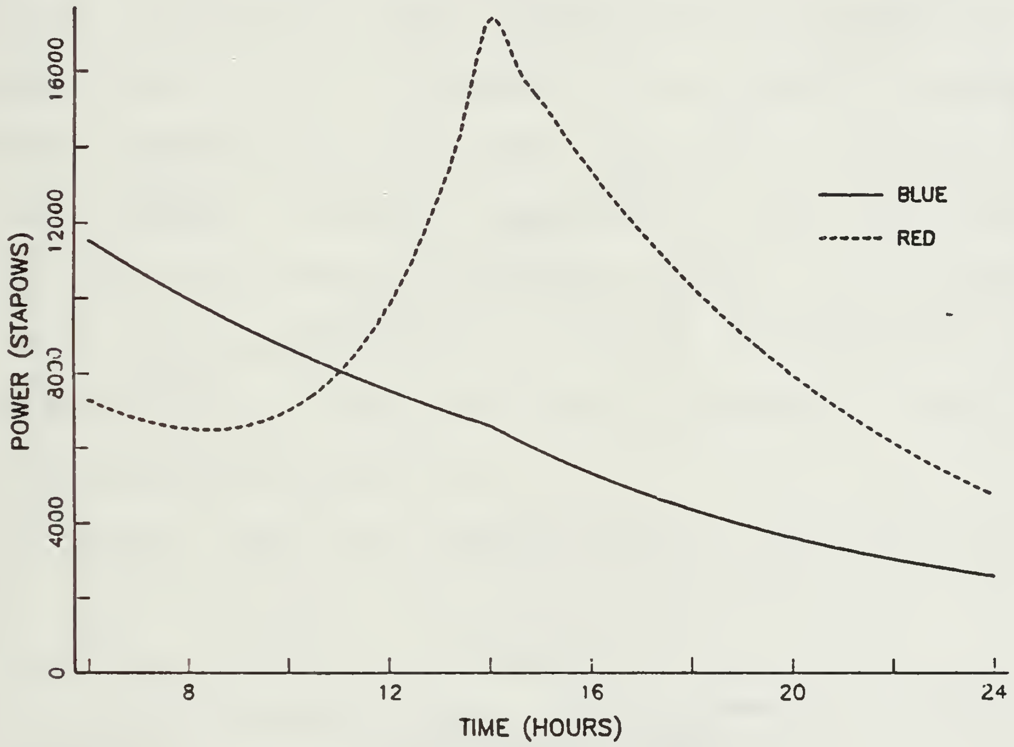

Figure 4-11 Power Curves, Second Update

```
Feasibility restored by plan:
   TIME      BLUE UNIT   ON    RED UNIT      CHEM OR CONV
   10.0          2                1              CHEM
   12.0          2                2              CHEM

 Enter time of update (hrs since T = 0)
  (in none, enter 999 to terminate program)
?
10
```

Figure 4-12 Feasible Plan, Second Update

To restore feasibility in this more seriously unbalanced situation, both red entities receive chemical fires, with the approaching tank division again being fired upon at maximum range. Restored feasibility is shown in the power curves in Figure 4-13.

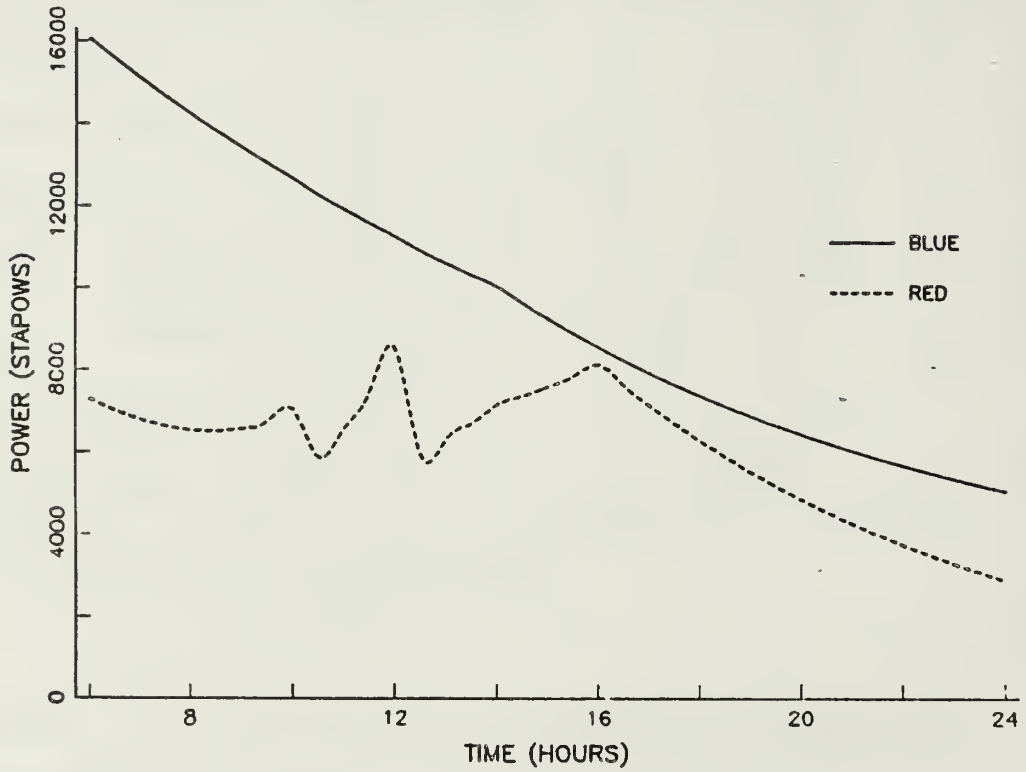

Figure 4-13 Power Curves, Second Update Plan Restoring Feasibility

C. THIRD UPDATE

At time T = 10, with the red tank division now 4 hours from contact, red fires a persistent chemical agent attack against the 1st Brigade, apparently in preparation for the arrival of the approaching force. Shifting the planning to the brigade level, the 1st Brigade has two armor battalions committed, one armor battalion as a brigade reserve, and its

direct support field artillery battalion. In addition, the division has allocated its three uncommitted units to the 1st Brigade for planning purposes. The intelligence module indicates that in addition to the red MRD opposing the brigade, the red tank division has two tank regiments 40 kilometers away with one regiment directed against each of the brigade's committed battalions. The red tank division's remaining units are a tank regiment and a motorized rifle regiment (MRR), both 60 kilometers away, and both apparently directed against the battalion that did not receive the chemical attack. Red has apparently fired the chemical mission and will commit one regiment of the tank division to fix the flank, with the main attack through the second battalion using the remaining three regiments. The input data are listed at Table 4-4.

As before, MOPP and feasibility are determined (Figure 4-14).

The power curves show that infeasibility occurs at T = 10 hours, the time of the chemical strike on the blue armor battalion (Figure 4-15).

As the program finds a feasible plan, attrition coefficients are again entered when requested. In this step, since a blue unit is contaminated, a decontamination schedule must also be found. The feasible plan is reported as shown in Figure 4-16.

TABLE 4-4

PROGRAM DEMONSTRATION, THIRD UPDATE

TIME = 10 HOURS

BLUE

ID NO	TYPE UNIT	BIP	STATE	DIST	SPEED	DESIRED PROP.	CHEM THRT	OPP UNIT	ATT. RED	COEFF. BLUE
1	ARM BN	1000	1	0	10	.4	4	2	.1	.05
								4	.1	.05
								5	.1	.05
								6	.1	.05
2	ARM BN	1000	1	5	10	.4	4	NC	.1	.05
3	FA BN	1800	1	0	10	.45	4	NC	.1	.02
4	FA BN	1800	1	0	10	.45	4	NC	.1	.02
5	HELO CO	800	1	20	40	.15	4	NC	.2	.1
6	ARM BN	1000	1	10	10	.4	4	NC	.1	.05
7	ARM BN	1000	1	0	10	.4	6	1	.1	.05
								3	.1	.05

RED

1	MRD-	7000	.8	0	10	-	-	7	-	-
2	MRD-	7000	.8	0	10	-	-	1	-	-
3	TK RGT	3600	1	40	10	-	-	7	-	-
4	TK RGT	3600	1	40	10	-	-	1	-	-
5	TK RGT	3600	1	60	10	-	-	1	-	-
6	MRR	3000	1	60	10	-	-	1	-	-

Recommended MOPP:

BLUE unit	1 ,	MOPP	2
BLUE unit	2 ,	MOPP	2
BLUE unit	3 ,	MOPP	2
BLUE unit	4 ,	MOPP	2
BLUE unit	5 ,	MOPP	2
BLUE unit	6 ,	MOPP	2
BLUE unit	7 ,	MOPP	4

Situation infeasible. Preparing feasible plan.

Figure 4-14 Result of Third Update

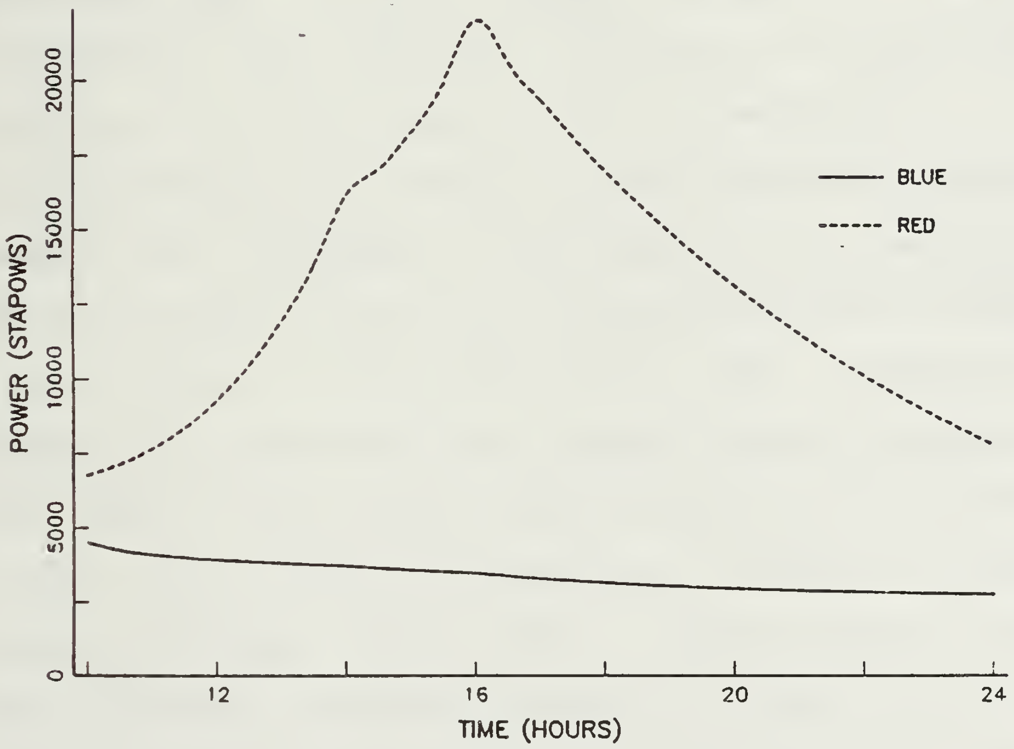

Figure 4-15 Power Curves, Third Update

Feasibility restored by plan:

TIME	BLUE UNIT	ON	RED UNIT	CHEM OR CONV
10.0	3		1	CONV

T = 10.0000000 , BLUE unit 7
begin move to decon site

10.0	4		2	CHEM
11.0	3		1	CHEM
12.0	3		3	CHEM
15.0	2		3	CONV
12.0	4		4	CHEM

Figure 4-16 Feasible Plan, Third Update

Not surprisingly, since the contaminated unit is recommended to move to the decontamination site immediately, the MOPP degradation and the continuing production of casualties is stopped soonest, and a field artillery battalion takes the opposing red force under conventional fire. A weakness of the program is that it allows a contaminated maneuver unit to withdraw for decontamination upon commitment of any blue unit to replace it, not necessarily another ground-occupying unit such as armor or infantry. Obviously, the contaminated unit's position (or an uncontaminated position nearby) must continue to be occupied to prevent discontinuity in the force's front line. This plan again interdicts approaching red units with chemical fires at maximum range. After three chemical strikes, however, the value of chemical missions increases until commitment of the brigade reserve armor battalion to the contaminated battalion's sector at T = 15 hours becomes a better option. This time is significant in that the same

red tank regiment opposing this armor battalion would have arrived at the battle position at T = 14, but the chemical strike at T = 12 delayed its arrival, making this the preferred option. The last course of action required to restore overall feasibility is again a chemical strike since it is still a better value than the now-remaining courses of action, given the parameters used in the selection. The program is terminated at this point.

The scenario demonstrates the use of the CW module application program in analyzing a situation and, using the precepts of the GVS, obtaining a plan to restore feasibility under conditions of chemical warfare.

V. CONCLUSIONS AND FUTURE DIRECTIONS

A. CONCLUSIONS

A chemical warfare module for the AirLand Advanced Research Model is described. Basic concepts of the CW module are demonstrated in an application program running a representative combat scenario. The module represents the key chemical staff functions of planning chemical weapons employment, determining MOPP guidance, and scheduling and allocating decontamination support.

The module is centered on the ALARM planning algorithm proposed by Fletcher [Ref. 5], successfully adding Kilmer's value concept [Ref. 3] to the decision rule for course of action selection. It incorporates the logical basis to integrate chemical warfare conditions fully into the ALARM planning model.

The application program generalizes previous implementations of the Generalized Value System and the planning algorithm. It performs planning at multiple organizational levels and for multiple engagements. Its interactive structure provides the basis for development of a staff planning and training aid or decision support system.

In terms of further development of ALARM, the program can assist efforts to obtain data for an eventual

determination of the dimensions of derived power of support entities. This can be done by inferring the effects on inherent power of supported units by decontamination units. The program also supports further studies into the nature of power synergism among entities by analyzing multiple engagements and comparing results in terms of power.

B. FUTURE DIRECTIONS

The logical framework for a chemical warfare module for ALARM is provided in this thesis as well as a computer program implementing it. Further development of the module to give it broader utility could include:

- Addition of NBC reconnaissance planning and other planning aspects of contamination avoidance when doctrinal and organizational issues are more settled. An effort might be made to use the CW module and the application program, with suitable additions, as tools to investigate reconnaissance issues.

- Addition of other chemical delivery means such as missiles and air. This would add a deeper dimension to the chemical employment model necessary for a full portrayal of AirLand Battle.

Full incorporation of the module in ALARM requires the reflection of CW conditions throughout the planning model and the preparation of appropriate interfaces with the module, as follows:

- The Cartesian space network must record and track contaminated units and terrain reported by the execution model and movement planning must account for contamination. As part of NBC reconnaissance planning, decisions must be made whether to cross contaminated terrain and accept the MOPP degradation, decontamination requirements, and possibility of casualties, or avoid it. These decisions are made by comparing the effects

of the alternatives on affected units' power functions using future state decision making.

- The execution model must have a reasonably full, accurate, and responsive depiction of chemical warfare. The Vector-in-Commander (VIC) model has a good developmental chemical module and is a candidate for an execution model in that respect.

In a wider context, ALARM developments that will enable improvements to the CW module, or that the CW module may assist in deriving, include:

- The nature of power synergism among entities, as discussed in Section A of this chapter.

- The appropriate value or values for the utility coefficient G in the Usefulness Value equation (Eqn 2.9).

- The expression and dimensions of derived power as discussed in Section A of this chapter.

Finally, further development of the application program requires the following considerations:

- Practical application of the program will require expanding the number and types of units modelled, and expanding and adding mission profiles along the lines that field artillery and attack helicopters are modelled.

- When updated chemical employment procedures are available, weather and collateral damage preclusion factors can be added.

- As on-going MOPP degradation studies produce more complete data, this aspect of subroutines CHDEF and CHDCON can be expanded to incorporate the new information.

- An expanded program will require further verification and validation.

- Development of the program as a training aid or decision support system will require consistent, verified Basic Inherent Power (BIP) values for all entities in the model. Studies planned for the next year at the Naval Postgraduate School will address this need for ALARM and

such information can be adopted for this program. Program refinement and preparation of user instructions would also be required.

APPENDIX A

SUMMARY OF CHEMICAL WARFARE

A. CHEMICAL EMPLOYMENT

Chemical warfare (CW) is the direct use of chemical compounds to kill or injure people, plants, or animals, or to damage or destroy materiel. It is generally practiced in an anti-personnel role. The compounds used are called chemical agents, and may be classified in several ways. The most useful classification is by physiological effect. Most chemical agents fall into one of the categories listed in Table A-1.

Chemical agents may be employed as liquids, aerosols, or vapors, depending on their physical characteristics and the desired effects. They may also be classified as persistent, semi-persistent, or non-persistent, depending on how long the agent remains on the target in hazardous concentrations. Persistent agents like the blister agents and persistent nerve agents may last for days or weeks. Semi-persistent agents may last a few hours. Non-persistent agents usually dissipate within a few minutes to an hour.

Besides their physiological effects and persistency, candidate chemical agents must have qualities that allow them to be delivered to a target. They must be stable in storage and under delivery conditions. For example, the

TABLE A-1

TYPES OF CHEMICAL AGENTS

TYPE	EFFECT
Nerve	Inhibits the enzyme cholinesterase, causing general collapse of central nervous system. Usually lethal. Long uncertain recovery period for survivors.
Blister	Damages body tissue, causing various types of lesions on skin, damage to lungs and eyes from vapor. Usually not lethal, but long recovery required.
Blood	Prohibits absorption of oxygen by blood, causing suffocation. Usually lethal.
Choking	Damages lungs, causing fluid buildup, "dry land drowning." Usually lethal.
Incapacitating	Various mechanisms, reducing ability to perform normally. Not lethal.

heat and pressures experienced by an artillery round must not alter or destroy the agent. It must also be practical to deliver the agent in adequate concentrations to have the desired effects on the target. One problem with chemical agent delivery in general is that producing the required concentration on the target to reach a threshold of effectiveness requires a relatively large number of munitions delivered within a short period of time. It is often difficult to dedicate sufficient fire support assets to chemical missions.

Once an effective concentration is reached, however, the results can be much greater than those achievable by an

equal number of conventional munitions. In addition to producing casualties, employment of chemicals causes personnel to don cumbersome protective clothing and to operate in a protected posture. This hinders efficient performance of most tasks, reducing speed and accuracy. Use of persistent agents creates a need to spend time and divert assets for eventual decontamination, further slowing the enemy's tempo of operations. Additionally, casualties who survive a chemical attack can have more effect on the opposing force's ability to operate than those who die. Individuals injured by chemical agents are not able to perform their duties and can create a huge drain on medical, transportation, and supply support, diverting them from other tasks directly supporting combat.

Other delivery considerations include weather, terrain, vegetation, and human construction. These factors can make target effects very uncertain and add to the difficulty of effective employment.

The U.S. has a no-first-use policy for chemical warfare. It maintains a stockpile of chemical weapons for deterrence: to have the ability to respond in kind to a chemical attack and thus put an enemy under the same difficult conditions. Should deterrence fail, U.S. policy is to retaliate in kind in order to encourage the opponent to cease use of chemical weapons as soon as possible.

The Soviet Union maintains the most extensive CW capability in the world. It regularly trains in the use of chemical agents and is apparently engaged in a continuous search for new agents. The U.S. retaliatory stockpile is aging and increasingly ineffective, and production of new munitions has been delayed.

B. CHEMICAL DEFENSE

Chemical defense consists of three aspects: contamination avoidance, protection, and decontamination. Adequate equipment, doctrine, and training must be available in all three areas in order to minimize the effects of enemy chemical employment.

Contamination avoidance involves the diligent use of chemical detection and alarm equipment and chemical reconnaissance in order to know when and where chemical contamination is present and thus avoid contact with it. This is the most basic and obviously cheapest approach to chemical defense. In practice, it is difficult to determine the best organization and equipment levels and how best to employ them.

Protection is the use of individual or collective protective equipment to prevent exposure of the body to chemical agents. Individual protection is achieved with a protective mask and hood and chemical protective clothing. Unfortunately, encapsulation of the body in this way causes loss of peripheral vision and depth perception, loss of

physical dexterity, and retention and build up of body heat. In even moderate weather conditions heat stress can quickly cause casualties. A flexible system called Mission Oriented Protective Posture (MOPP) is used to standardize protection levels and allow a trade-off between the chemical threat and mission accomplishment. MOPP consists of five levels of protection produced by gradually donning components of the protective ensemble, thus reducing the amount of time necessary to achieve complete protection in a chemical attack, but allowing soldiers to perform their duties without the heat stress of full encapsulation. The MOPP levels are shown in Table A-2.

Collective protection ranges from chemical filters and environmental control systems in combat vehicles and chemical protective shelters to field expedient shelters using filters and blower systems in existing buildings.

Decontamination is the removal or neutralization of chemical agents from personnel, equipment, or terrain in order to reduce of remove the hazard and permit operation without the encumbrance of protective equipment. Hasty decontamination is the use of individual decontamination kits by the soldier on his own clothing, skin, and personal equipment; the use of crew contamination equipment on limited areas of vehicles or crew served equipment; or quick wash-downs with water and small amounts of decontaminants. Its purpose is to remove small amounts of contamination or

TABLE A-2

MISSION ORIENTED PROTECTIVE POSTURE

MOPP LEVEL	OVERGARMENT	BOOTS	MASK,HOOD	GLOVES
0	Carried	Carried	Carried	Carried
1	Worn, open or closed	Carried	Carried	Carried
2	Worn, open or closed	Worn	Carried	Carried
3	Worn, open or closed	Worn	Worn, hood up or down	Carried
4	Worn, closed	Worn	Worn, hood down	Worn

reduce the level of contamination in order to decrease the hazard and permit relaxation of protective posture. Hasty decontamination is usually a stopgap measure until more time is available for more thorough decontamination. Deliberate decontamination is essentially complete removal or neutralization of chemical agents supported by a chemical decontamination unit. It is a relatively time consuming process involving use of large quantities of water and decontaminants. It usually requires the contaminated unit to move to an established decontamination site.

Decontamination units are in short supply in the U.S. Army, relative to the possible requirement for their services. Each division (less light infantry) has one organic chemical company which also has screening smoke and reconnaissance missions. Each corps has one chemical

company on active duty and may be assigned one or more reserve companies after mobilization. Light infantry divisions are supported by chemical companies assigned to the corps. In operation, the division may allocate one decontamination platoon to support each brigade.

APPENDIX B

APPLICATION - COMPUTER PROGRAM

```
**********************************************************************
*                                                                    *
*     PURPOSE:  Demonstrate a basic Chemical Module for ALARM, by    *
*               applying the Generalized Value System and Fletcher's *
*               planning algorithm in an example combat scenario     *
*               incorporating the planning of chemical weapons       *
*               employment, the determination of appropriate MOPP    *
*               guidance, and the allocation and timing of           *
*               decontamination support.                             *
*               The program uses interactive data input, to form the *
*               basis for a planning/decision aid, as well as an     *
*               ALARM module.                                        *
*                                                                    *
*     I/O:      Data input and results output are through the        *
*               terminal, in order to develop the program as a       *
*               decision/training/planning aid.  Adapting the        *
*               program logic to ALARM, the terminal interfaces      *
*               represent calls between modules.  For example,       *
*               information about RED entities in ALARM would be     *
*               obtained for the planning module by interface with   *
*               the intelligence module.                             *
*                                                                    *
**********************************************************************

***************************************************************
*     *** VARIABLE DECLARATIONS, DIMENSIONS, INITIALIZATION ***
***************************************************************

      INTEGER  NX,XTYPE(0:10),XMISS(10),XTHRT(10),XTGT(0:10,0:25)
      INTEGER  XCOM(0:10),CFLAG(10),XTGTN(10),ITIMP,ITTD,CONFL(10,0:25)
      INTEGER  CHEMFL(10,0:25)

      INTEGER  NY,YTYPE(10),YMISS(10),YTGT(0:10,0:25),YTGTN(10)

      INTEGER  FEAS,PLAN,BLUE(20),RED(20),IT4,ITDEC,IT1T,ITT3,ITT4,ITT
      INTEGER  FLAG3(10,0:70),FLAG4(10,0:70),Z(0:10),COM,FLAGC
      INTEGER  MOPP(10),NCON,CONTAM(10),DECON,DEC(20),NQ,STACK(10)
      INTEGER  FLAGA(10,10),PRNCT

      REAL     XK(10),XBIP(10),XSTATE(0:10),XDIST(0:10),XSPEED(0:10)
      REAL     XDP(10),XABIP(0:10),XD(0:10),XTENG(0:10,0:25),XDI(10)
      REAL     XATT(10,10),XTA(0:10),XSIP(0:10,0:50),XSIPTA(10),XTP(10)
      REAL     XRNG(10),SABIP(10),XTABIP,CP(10),VAL(0:10,0:50),XCATT
      REAL     XSTATI(10),DECDIS,XSPEDI(10),XDSTAT(0:10),XDISTA(10)
      REAL     XDABIP(0:10),XDDIST(0:10),XDISTI(10),XCSIP(0:10,0:50)
      REAL     XTSIP(0:50),XTSIPT(0:50),XSIP1(0:10,0:50),XDD(10)
      REAL     XSIP1T(0:10,0:50),XTR(10),DECVAL,XCSIPI(0:10,0:50)
      REAL     XMOVE(10)

      REAL     YK(10),YBIP(10),YSTATE(10),YDIST(10),YSPEED(10)
      REAL     YABIP(10),YD(10),YTP(10),YLOC(0:10,0:50),YDC(10),YTAC(10)
      REAL     YATT(10,10),YTA(10),YSIP(0:10,0:50)
      REAL     YSIP1(0:10,0:50),YSPEDI(10),YDISTI(10),YDI(10),YTAI(10)
      REAL     YSIP1T(0:10,0:50),YTSIP(0:50),YTSIPT(0:50)

      REAL     TU,TP,TEND,TD,TSTEP,TDEC,G,UV,RATIO,TDECN(20),TTD
      REAL     POWRAT,END4,CRDS,ARDS,DCRDS,CPC,DPC,CHRDS,TC(10),C
      REAL     TX,TDMOVE,DTIME(20),TDCON(10),TDC(10),TIME(20),ENGAGE(20)

      CHARACTER*1  YCHEM,XEMP,PERS(10)
      CHARACTER*4  TYPE(20)

      DATA  TP/0./,TU/0./,TSTEP/0.5/,G/-3./,C/0.01047/,NQ/0/

************************************************************************
```

```
***********************************
*     *** INPUT SITUATION ***
***********************************
*                    *** BLUE ***
*                    ************
       PRINT *,'To terminate program during data input, enter 999'
       PRINT *,'in response to any prompt for data.'
       PRINT *
       PRINT *, 'At time T = 0'
10    DO 30  I = 1,10
         TDC(I) = 0.
         STACK(I) = 0
         XABIP(I) = 0.
         YABIP(I) = 0.
         TDCON(I) = 0.
         XTP(I) = 0.
         YTP(I) = 0.
         XTYPE(I) = 0
         YTYPE(I) = 0
         CFLAG(I) = 0
         CONTAM(I) = 0
         XMOVE(I) = 999.
         DO 31 ITT = 0,50
            XSIP(I,ITT) = 0.
            YSIP(I,ITT) = 0.
31       CONTINUE
30    CONTINUE
       DO 20  ITT = 0,50
          XTSIPT(ITT) = 0.
          YTSIPT(ITT) = 0.
20    CONTINUE
       PRINT *
       PRINT *, 'Enter the number of blue entities (units):'
       READ *, NX
       IF (NX .EQ. 999) GO TO 1000
       PRINT *, 'For each Blue entity, enter the information requested.'
       PRINT *,' (units under chemical attack or contaminated should be'
       PRINT *,' entered last)'
       DO 100  I = 1,NX
          PRINT *
          PRINT *,'   Blue entity (ID no.)',I,':'
          PRINT *,'        Unit Type (enter no. 1-6)'
          PRINT *,'             1 - Armor Div '
          PRINT *,'             2 - Armor Bde '
          PRINT *,'             3 - FA Bn (203-mm SP)'
          PRINT *,'             4 - Atk Helo Co'
          PRINT *,'             5 - Armor Bn'
*        PRINT *,'            6 - Chem Co (NBC Def)'
          READ *, XTYPE(I)
          IF (XTYPE(I) .EQ. 999) GO TO 1000
          IF (XTYPE(I) .EQ. 3) THEN
             XRNG(I) = 20.
          ELSE IF (XTYPE(I) .EQ. 4) THEN
             XRNG(I) = 60.
          ELSE
             XRNG(I) = 5.
          END IF
          PRINT *,'        Mission (enter no. 1-2)'
          PRINT *,'             1 - Attack'
          PRINT *,'             2 - Defend'
          READ *, XMISS(I)
          IF (XMISS(I) .EQ. 999) GO TO 1000
          IF (XMISS(I) .EQ. 1) THEN
              XK(I) = 1.
          ELSE
```

```
      XK(I) = 3.
   END IF
   PRINT *,'        Basic inherent power (BIP) in STAPOWS'
   READ *, XBIP(I)
   IF (XBIP(I) .EQ. 999.) GO TO 1000
   PRINT *,'        State, at T = 0'
   PRINT *,'             (SQRT(% personnel x % equipment))'
   READ *, XSTATE(I)
   IF (XSTATE(I) .EQ. 999.) GO TO 1000
   XSTATI(I) = XSTATE(I)
   PRINT *,'        Distance from assigned battle position (km)'
   READ *, XDIST(I)
   IF (XDIST(I) .EQ. 999.) GO TO 1000
   XDISTA(I) = XDIST(I)
   PRINT *,'        Average speed of travel (when moving)(km/hr)'
   READ *, XSPEED(I)
   IF (XSPEED(I) .EQ. 999.) GO TO 1000
   XSPEDI(I) = XSPEED(I)
   IF (XDIST(I) .EQ. 0.) THEN
     PRINT *,'        Time unit arrived at battle position '
     PRINT *,'        (hrs since T = 0)'
     READ *, XTA(I)
     IF (XTA(I) .EQ. 999.) GO TO 1000
   ELSE
     XTA(I) = (XDIST(I)/XSPEED(I)) + TP
   END IF
   XTR(I) = XTA(I)
   IF (XTYPE(I) .EQ. 4)  XTR(I) = TP
   IF (TP .GT. 0.) THEN
     PRINT *,'        Time unit entered scenario (area of'
     PRINT *,'        interest)(explicitly or as part of parent'
     PRINT *,'        unit) (hrs since T = 0)'
     READ *,  XTP(I)
     IF (XTP(I) .EQ. 999.)  GO TO  1000
     PRINT *,'        Distance of unit from battle position at'
     PRINT *,'        that time.'
     READ *,  XDISTI(I)
     IF (XDISTI(I) .EQ. 999.)  GO TO 1000
   ELSE
     XDISTI(I) = XDIST(I)
   END IF
   IF (XDISTI(I) .GT. 0.) THEN
     XD(I) = (LOG(XDISTI(I)))/(XDISTI(I)/XSPEED(I))
   ELSE
     XD(I) = 0.
   END IF
   XDI(I) = XD(I)
   PRINT *,'        Desired proportional power of this type '
   PRINT *,'        unit in Blue force, for this mission'
   READ *, XDP(I)
   IF (XDP(I) .EQ. 999.) GO TO 1000
   IF (XTYPE(I) .EQ. 3) THEN
 PRINT *,'        Daily allocation of chemical artillery rounds'
     READ *,  CRDS
     IF (CRDS .EQ. 999.) GO TO 1000
     PRINT *,'        Daily allocation of artillery rounds '
     PRINT *,'          (all types)'
     READ *,  ARDS
     IF (ARDS .EQ. 999.) GO TO 1000
     PRINT *,'        Desired daily allocation of chemical '
     PRINT *,'         artillery rounds '
     READ *,  DCRDS
     IF (DCRDS .EQ. 999.) GO TO 1000
     CPC = CRDS/ARDS
```

```
            DPC = DCRDS/ARDS
         END IF
         PRINT *,'        Chemical threat (enter no. 1-6)'
         PRINT *,'              1 - None '
         PRINT *,'              2 - Unlikely'
         PRINT *,'              3 - Moderate'
         PRINT *,'              4 - High'
         PRINT *,'              5 - Immediate'
         PRINT *,'              6 - Under chemical attack/'
         PRINT *,'                   in contaminated area'
         READ *, XTHRT(I)
         IF (XTHRT(I) .EQ. 999) GO TO 1000
         IF (XTHRT(I) .EQ. 6) THEN
            PRINT *,'        Persistent or non-persistent agent (P/N)?'
            READ '(A)', PERS(I)
               IF (PERS(I) .EQ. '999') GO TO 1000
               IF (PERS(I) .EQ. 'P') THEN
                  PRINT *,'       Time of chemical attack (hours since T=0)'
                  READ *,  TC(I)
                  IF (TC(I) .EQ. 999.) GO TO 1000
               END IF
         ELSE
            PERS(I) = 'X'
         END IF
         PRINT *,'        Number of Red entities opposing this unit'
         PRINT *,'              (0 = Not committed)'
         READ *, XTGTN(I)
         IF (XTGTN(I) .EQ. 999) GO TO 1000
         IF (XTGTN(I) .EQ. 0) THEN
            XCOM(I) = 0
            XTA(I) = 999.
         ELSE
            XCOM(I) = 1
            PRINT *,'        Red entities opposing this unit (ID no.)'
            PRINT *,'             (Enter one at a time)'
            DO 110  J = 1,XTGTN(I)
               READ *, XTGT(I,J)
               IF (XTGT(I,J) .EQ. 999) GO TO 1000
110      CONTINUE
         END IF
         DO 130  K = 1,XTGTN(I)
            PRINT *,'       Attrition coefficient for BLUE unit',I
            PRINT *,'         on RED unit',XTGT(I,K)
            READ *, XATT(XTGT(I,K),I)
            IF (XATT(XTGT(I,K),I) .EQ. 999.) GO TO 1000
            PRINT *,'       Attrition coefficient for RED unit',XTGT(I,K)
            PRINT *,'         on BLUE unit',I
            READ *, YATT(I,XTGT(I,K))
            IF (YATT(I,XTGT(I,K)) .EQ. 999.) GO TO 1000
            CONFL(I,K) = 1
            CHEMFL(I,K) = 0
130     CONTINUE
         DO 140  J = 1,25
            XTENG(I,J) = 9999.
140     CONTINUE
100   CONTINUE
      PRINT *,'          Distance from FLOT to decon site (km)'
      READ *,  DECDIS
      IF (DECDIS .EQ. 999.) GO TO 1000
*              *****************
*                 *** RED ***
*              *****************
      PRINT *
      PRINT *,'Enter the number of Red entities (units):'
      READ *, NY
```

```
IF (NY .EQ. 999) GO TO 1000
PRINT *,'For each Red entity, enter the information requested'
DO 200  J = 1,NY
   PRINT *
   PRINT *,'   Red entity (ID no.)',J,':'
   PRINT *,'        Unit type (enter no. 1-4)'
   PRINT *,'                1 - Tk Div'
   PRINT *,'                2 - MR Div'
   PRINT *,'                3 - Tk Rgt'
   PRINT *,'                4 - MR Rgt'
   READ *, YTYPE(J)
   IF (YTYPE(J) .EQ. 999) GO TO 1000
   PRINT *,'        Mission (enter no. 1-2)'
   PRINT *,'                1 - Attack'
   PRINT *,'                2 - Defend'
   READ *, YMISS(J)
   IF (YMISS(J) .EQ. 999) GO TO 1000
   IF (YMISS(J) .EQ. 1) THEN
      YK(J) = 1.
   ELSE
      YK(J) = 3.
   END IF
   PRINT *,'        Basic inherent power (BIP) in STAPOWS'
   READ *, YBIP(J)
   IF (YBIP(J) .EQ. 999.) GO TO 1000
   PRINT *,'        State, at T = 0'
   PRINT *,'                (SQRT(% personnel x % equipment))'
   READ *, YSTATE(J)
   IF (YSTATE(J) .EQ. 999.) GO TO 1000
   PRINT *,'        Distance from battle position (km)'
   READ *, YDIST(J)
   IF (YDIST(J) .EQ. 999.) GO TO 1000
   PRINT *,'        Average speed of travel (when moving)(km/hr)'
   READ *, YSPEED(J)
   IF (YSPEED(J) .EQ. 999.) GO TO 1000
   YSPEDI(J) = YSPEED(J)
   IF (YDIST(J) .EQ. 0.) THEN
     PRINT *,'        Time unit arrived at battle position '
     PRINT *,'         (hrs since T = 0)'
     READ *, YTA(J)
     IF (YTA(J) .EQ. 999.) GO TO 1000
   ELSE
     YTA(J) = (YDIST(J)/YSPEED(J)) + TP
   END IF
   YTAI(J) = YTA(J)
   YTAC(J) = YTA(J)
   IF (TP .GT. 0.) THEN
     PRINT *,'        Time unit entered scenario (area of'
     PRINT *,'        interest)(explicitly or as part of parent'
     PRINT *,'        unit) (hrs since T = 0)'
     READ *,  YTP(J)
     IF (YTP(J) .EQ. 999.)  GO TO 1000
     PRINT *,'        Distance from battle position at that time'
     READ *,  YDISTI(J)
     IF (YDISTI(J) .EQ. 999.)  GO TO 1000
   ELSE
     YDISTI(J) = YDIST(J)
   END IF
   IF (YDISTI(J) .GT. 0.) THEN
     YD(J) = (LOG(YDISTI(J)))/(YDISTI(J)/YSPEED(J))
   ELSE
     YD(J) = 0.
   END IF
   YDI(J) = YD(J)
```

```
            YDC(J) = YD(J)
            YTGTN(J) = 0
            DO 230  I = 1,NX
               DO 240  K = 1,XTGTN(I)
                  IF (XTGT(I,K) .EQ. J) THEN
                     YTGTN(J) = YTGTN(J) + 1
                     YTGT(J,YTGTN(J)) = I
                  END IF
240            CONTINUE
230         CONTINUE
200   CONTINUE
*                    ***********************
*                       *** CW STATUS ***
*                    ***********************
         PRINT *,'Has Red employed chemical weapons (Y/N)?'
         READ '(A)', YCHEM
         IF (YCHEM .EQ. '999') GO TO 1000
         IF (YCHEM .EQ. 'Y') THEN
            PRINT *,'Does Blue have chemical employment'
            PRINT *,'      authority (Y/N)?'
            READ '(A)', XEMP
            IF (XEMP .EQ. '999') GO TO 1000
         ELSE
            XEMP = 'N'
         END IF
*                    ***********************
*                       *** TIME SPAN ***
*                    ***********************
         PRINT *,'Enter mission duration (no. hours from T=0)'
         READ *, TEND
         IF (TEND .EQ. 999.) GO TO 1000
***************************************************************************
*********************************************************************
*    *** DETERMINE APPROPRIATE MOPP STATUS, INITIAL FEASIBILITY ***
*********************************************************************
         DO 250  I = 1,NX
            DO 251  J = 1,XTGTN(I)
               IF ((XTYPE(I) .EQ. 3).OR.(XTYPE(I) .EQ. 4)) THEN
                  XTENG(I,J) = XTA(I)
               ELSE
                  XTENG(I,J) = MAX(XTA(I),YTA(XTGT(I,J)))
               END IF
251         CONTINUE
250   CONTINUE
         DECON = 0
         TDMOVE = 0.
         XCATT = 0.
         CALL CHDEF(XTHRT,MOPP,C,CONTAM,NCON,NX,XK,XBIP,XDIST,XSPEED,
     2              XSTATE,XTGTN,XTGT,XATT,XCOM,XABIP,XSIP,XSIPTA,XTA,
     3              XTENG,NY,YK,YBIP,YDIST,YSPEED,YSTATE,YTGTN,YTGT,YABIP,
     4              YSIP,YATT,FEAS,TD,TP,TEND,TSTEP,TC,PERS,DECDIS,TDEC,
     5              TDMOVE,DECON,NQ,STACK,TDCON,XSPEDI,XSTATI,XD,YD,XTYPE,
     6              XTP,YTP,TU,XDISTI,YDISTI,CFLAG,YTA,TDC,XCATT,CONFL,
     7              CHEMFL,XTSIP,YTSIP,XTR,YDC,YTAC,YSPEDI,XMOVE)
         IF (FEAS .EQ. 1) THEN
            PRINT *
            PRINT *,' Situation feasible at this time.'
            PRINT *
            PRINT *,' Enter time of update (hrs since T = 0)'
            PRINT *,'  (if none, enter 999 to terminate program)'
            READ *, TP
            IF (TP .EQ. 999) GO TO 1000
```

```
          PRINT *
          PRINT *,' At time T = ',TP
          GO TO 10
       ELSE
          PRINT *
          PRINT *,' Situation infeasible.  Preparing feasible plan.'
          PRINT *
       END IF
*********************************************************************
************************************************************
*    *** PREPARE COURSES OF ACTION TO RESTORE FEASIBILITY ***
************************************************************
*                   *** INITIALIZE ***
*                   ******************

      DO 260  N = 1,NCON
         DO 261  T = TP,TEND,TSTEP
            ITT = IFIX(T/TSTEP)
            XCSIPI(CONTAM(N),ITT) = XSIP(CONTAM(N),ITT)
261      CONTINUE
260   CONTINUE

      TDEC = TD

      DO 301  I = 1,NX
         DO 300  TX = TP,TEND+10.,TSTEP
             ITT = IFIX(TX/TSTEP)
             FLAG3(I,ITT) = 0
             FLAG4(I,ITT) = 0
300      CONTINUE
301   CONTINUE

      PLAN = 1
      TDECN(PLAN) = TDEC

      XTABIP = 0.

      DO 310  I = 1,NX
         Z(I) = 0
         XTABIP = XTABIP + XABIP(I)
         DO 312  T = TP,TEND,TSTEP
            ITT = IFIX(T/TSTEP)
            IF (XTYPE(I) .EQ. 4) THEN
               XSIP1(I,ITT) = XSIPTA(I)
            ELSE
               XSIP1(I,ITT) = XSIPTA(I)*(EXP(-0.03*(T-XTR(I))))
            END IF
312      CONTINUE
         DO 311  N = 1,NY
            FLAGA(I,N) = 0
311      CONTINUE
310   CONTINUE

      DO 330  J = 1,NY
         DO 331 T = TP,TEND,TSTEP
            ITT = IFIX(T/TSTEP)
            YSIP1(J,ITT) = YSIP(J,ITT)
331      CONTINUE
330   CONTINUE

320   POWRAT = 0.
      FLAGC = 0
      DECON = 0
      TDMOVE = 0.

      DO 400  I = 1,NX
         SABIP(I) = 0.
*                  ******************************
*                     *** CHECK VIABILITY ***
*                  ******************************

         IF (XCOM(I) .EQ. 0) THEN
            DO 401  L = 1,NX
```

```
            IF (XTYPE(L) .EQ. XTYPE(I))  SABIP(I) = SABIP(I)+XABIP(L)
401       CONTINUE
40        DO 410  J = 1,NY
             DO 420  T = TP,TDEC,TSTEP
                ITT = IFIX(T/TSTEP)
                IF (T .LT. TDC(I)) GO TO 420
                YLOC(J,ITT) = YDISTI(J) - YSPEED(J) * (T - YTP(J))
                IF (YLOC(J,ITT) .LT. 0.)  YLOC(J,ITT) = 0.
                IF ((XTYPE(I) .EQ. 3).OR.(XTYPE(I) .EQ. 4)) THEN
                  IF (XRNG(I) .LT. (XDIST(I) + YLOC(J,ITT))) GO TO 420
                END IF
                IF ((XTYPE(I) .EQ. 3) .AND. ((FLAG3(I,ITT) .EQ. 1) .OR.
     2            (FLAG3(I,ITT+1) .EQ. 1)))  GO TO 420
                IF (XTYPE(I) .EQ. 4) THEN
                  XTA(I) = ((XDIST(I) + YLOC(J,ITT))/XSPEED(I)) + T
                  END4 = XTA(I) + 1. + (XTA(I) - T)
                  IT4 = IFIX(END4/TSTEP)
                  IF ((FLAG4(I,ITT).EQ.1).OR.(FLAG4(I,IT4+1).EQ.1))
     2            GO TO 420
                END IF
                IF ((XTYPE(I) .EQ. 3) .OR. (XTYPE(I) .EQ. 5)) THEN
                  XTA(I) = (XDIST(I)/XSPEED(I)) + T
                END IF
                IF (XTA(I) .GT. TDEC) GO TO 410
*                 *******************************
*                    *** DESIGNATE MISSION ***
*                 *******************************
                XTGTN(I) = XTGTN(I) + 1
                XTGT(I,XTGTN(I)) = J
                YTGTN(J) = YTGTN(J) + 1
                YTGT(J,YTGTN(J)) = I
                CONFL(I,XTGTN(I)) = 1
                CHEMFL(I,XTGTN(I)) = 0
                IF ((XTYPE(I) .EQ. 3).OR.(XTYPE(I) .EQ. 4)) THEN
                  XTENG(I,XTGTN(I)) = XTA(I)
                ELSE
                  XTENG(I,XTGTN(I)) =  MAX(XTA(I),YTA(J))
                END IF
                XTP(I) = T
                IF (FLAGA(I,J) .EQ. 0) THEN
                  PRINT *,' Enter attrition coefficient for BLUE unit ',I
                  PRINT *,'       on RED unit ',J
                  READ *, XATT(J,I)
                  IF (XATT(J,I) .EQ. 999) GO TO 1000
                  PRINT *,' Enter attrition coefficient for RED unit ',J
                  PRINT *,'       on BLUE unit ',I
                  READ *, YATT(I,J)
                  IF (YATT(I,J) .EQ. 999) GO TO 1000
                  FLAGA(I,J) = 1
                END IF
*                 **************************************************
*                    *** PLAN CHEMICAL STRIKE, IF APPROPRIATE ***
*                 **************************************************
                IF ((FLAGC .EQ. 1) .AND. (XEMP .EQ. 'Y')) THEN
                  JX = J
                  TX = T
                  CONFL(I,XTGTN(I)) = 0
                  CHEMFL(I,XTGTN(I)) = 1
                  CALL CHEMP(JX,TX,YSPEED,YSPEDI,YDC,YTAC,YLOC,YTYPE,
     2                    TSTEP,CHRDS,ITT,XCATT,YDISTI)
                END IF
*                 ******************************************
```

```
*                        *** DESIGNATE UNITS NEEDING DECON ***
*                     ******************************************

                    DO 440  N = 1,NCON
                      DO 450  M = 1,XTGTN(CONTAM(N))
                        IF (XTGT(I,XTGTN(I)).EQ. XTGT(CONTAM(N),M)) THEN
                          TDMOVE = XTA(I)
                          DECON = CONTAM(N)
                        END IF
450                 CONTINUE
                      IF (XCOM(CONTAM(N)) .EQ. 0) THEN
                        TDMOVE = T
                        DECON = CONTAM(N)
                      END IF
440               CONTINUE
*                     ****************************************************
*                        *** CHECK FEASIBILITY, RETURN NEW TD, FEAS ***
*                     ****************************************************

                    CALL POWER(NX,XK,XBIP,XDIST,XSPEED,XSTATE,XTGTN,XTGT,
     2                   XATT,XCOM,XABIP,XSIP,XSIPTA,XTA,XTENG,NY,YK,
     3                   YBIP,YDIST,YSPEED,YSTATE,YTGTN,YTGT,YABIP,
     4                   YSIP,YATT,FEAS,TD,TP,TEND,TSTEP,TC,C,PERS,
     5                   DECDIS,TDEC,TDMOVE,DECON,NQ,STACK,TDCON,
     6                   XSPEDI,XSTATI,XD,YD,XTYPE,XTP,YTP,TU,XDISTI,
     7                   YDISTI,CFLAG,YTA,TDC,XCATT,CONFL,CHEMFL,XTSIP,
     8                   YTSIP,XTR,YDC,YTAC,YSPEDI,XMOVE)
*     ****************************************************************
*       *** IF FEASIBILITY RESTORED AT TDEC, COMPUTE VALUE OF COA ***
*     ****************************************************************

                    IF (TD .GT. TDEC) THEN
                      ITDEC = IFIX(TDEC/TSTEP)
        UV = XBIP(I)*(1.-(EXP(G * XSIP(I,ITDEC)/XBIP(I))))/(1.-(EXP(G)))
                      CP(I) = SABIP(I) / XTABIP
                      IF ((XTYPE(I) .EQ. 3).AND.(FLAGC .EQ. 1)) THEN
                        VAL(I,ITDEC) = ((XDP(I)/CP(I))+(DPC/CPC))*UV/10000.
                      ELSE IF (XTYPE(I) .EQ. 3) THEN
              VAL(I,ITDEC)=((XDP(I)/CP(I))+((1.-DPC)/(1.-CPC)))*UV/10000.
                      ELSE
                        VAL(I,ITDEC) = ((XDP(I)/CP(I))+1.) * UV/10000.
                      END IF
                      IF (DECON .EQ. 0) THEN
                        DECVAL = 1.
                      ELSE
                        DECVAL = XSIP(DECON,ITDEC)/XCSIPI(DECON,ITDEC)
                      END IF
                      IF (DECVAL .GT. 1.5)  DECVAL = 1.5
                      IF (DECVAL .LT. 0.5)  DECVAL = 0.5
*                     *****************************
*                        *** SELECT BEST COA ***
*                     *****************************

                      RATIO = ((YSIP1(J,ITDEC) - (YSIP(J,ITDEC)-1.001))/
     2        ((XSIP1(I,ITDEC)-(XSIP(I,ITDEC)-1.001))*VAL(I,ITDEC)))
     3                 *DECVAL
                      IF (RATIO .GT. POWRAT) THEN
                        POWRAT = RATIO
                        BLUE(PLAN) = I
                        IF (FLAGC .EQ. 1) THEN
                          TYPE(PLAN) = 'CHEM'
                        ELSE
                          TYPE(PLAN) = 'CONV'
                        END IF
                        RED(PLAN) = J
                        TIME(PLAN) = T
                        ENGAGE(PLAN) = XTENG(I,XTGTN(I))
                        DEC(PLAN) = DECON
```

```
                  DTIME(PLAN) = TDMOVE
                  XDABIP(DEC(PLAN)) = XABIP(DEC(PLAN))
                  XDSTAT(DEC(PLAN)) = XSTATE(DEC(PLAN))
                  XDDIST(DEC(PLAN)) = XDIST(DEC(PLAN))
                  XDD(DEC(PLAN)) = XD(DEC(PLAN))
                  DO 470  TTD = TP,TEND,TSTEP
                    ITTD = IFIX(TTD/TSTEP)
                    XCSIP(DEC(PLAN),ITTD) = XSIP(DEC(PLAN),ITTD)
470            CONTINUE
                  TDECN(PLAN) = TD

                  DO 430  TT = TP,TEND,TSTEP
                    IT1T = IFIX(TT/TSTEP)
                    XSIP1T(I,IT1T) = XSIP(I,IT1T)
430            CONTINUE

                  DO 460  JJ = 1,NY
                    DO 461  TT = TP,TEND,TSTEP
                      IT1T = IFIX(TT/TSTEP)
                      YSIP1T(JJ,IT1T) = YSIP(JJ,IT1T)
461             CONTINUE
460            CONTINUE

                  DO 480  TPOW = TP,TEND,TSTEP
                    ITPOW = IFIX(TPOW/TSTEP)
                    XTSIPT(ITPOW) = XTSIP(ITPOW)
                    YTSIPT(ITPOW) = YTSIP(ITPOW)
480            CONTINUE

                END IF
              END IF

              XTGTN(I) = XTGTN(I)-1
              YTGTN(J) = YTGTN(J)-1

              IF (DECON .NE. 0) THEN
                XDIST(DECON) = XDISTA(DECON)
                XD(DECON) = XDI(DECON)
                XSTATE(DECON) = XSTATI(DECON)
                DECON = 0
                TDMOVE = 0.
              END IF

              YSPEED(J) = YSPEDI(J)
              YTA(J) = YTAI(J)
              YD(J) = YDI(J)

420         CONTINUE
410       CONTINUE

            IF ((XTYPE(I) .EQ. 3).AND.(FLAGC .EQ. 0)) THEN
              IF (CRDS .GE. 108.) THEN
                FLAGC = 1
                GO TO 40
              END IF
            ELSE IF ((XTYPE(I) .EQ. 3).AND.(FLAGC .EQ. 1)) THEN
              FLAGC = 0
            END IF

          END IF

400     CONTINUE

        IF (POWRAT .EQ. 0.) THEN
          COM = NX
          TIME(PLAN) = 0.
          BLUE(PLAN) = 0
          RED(PLAN) = 0
          ENGAGE(PLAN) = 0.
          TYPE(PLAN) = 'UNK '
          GO TO 900
        END IF
*                   **************************************
*                      *** IF FEASIBLE, OUTPUT PLAN ***
*                   **************************************
```

```
      IF (TDECN(PLAN) .GE. TEND) THEN
         DO 490  TPOW = TP,TEND,TSTEP
            ITPOW = IFIX(TPOW/TSTEP)
            XTSIP(ITPOW) = XTSIPT(ITPOW)
            YTSIP(ITPOW) = YTSIPT(ITPOW)
490     CONTINUE
         PRINT *
         PRINT *,'  Feasibility restored by plan:'
         PRINT *,'   TIME     BLUE UNIT  ON   RED UNIT      CHEM OR CONV'
         DO 500  N = 1,PLAN
            PRINT '(4X,F4.1,8X,I2,13X,I2,13X,A4)', ENGAGE(N),BLUE(N),
     2           RED(N),TYPE(N)
            IF (DEC(N) .NE. 0) THEN
               PRINT *, 'T = ',DTIME(N),', BLUE unit ',DEC(N)
               PRINT *, 'begin move to decon site'
            END IF
500     CONTINUE
         PRINT *
         PRINT *,'  Enter time of update (hrs since T = 0)'
         PRINT *,'   (if none, enter 999 to terminate program)'
         READ *, TP
         IF (TP .EQ. 999) GO TO 1000
         PRINT *
         PRINT *,'  At time T = ',TP
         GO TO 10
*                   ****************************************************
*                      *** IF INFEASIBLE, SAVE BEST COA AND REPEAT ***
*                   ****************************************************

      ELSE
         IF (XTYPE(BLUE(PLAN)) .EQ. 5) THEN
            XCOM(BLUE(PLAN)) = 1
            XTR(BLUE(PLAN)) = ENGAGE(PLAN)
         END IF
         IF (DEC(PLAN) .NE. 0) THEN
            PERS(DEC(PLAN)) = 'X'
            XABIP(DEC(PLAN)) = XDABIP(DEC(PLAN))
            XSTATE(DEC(PLAN)) = XDSTAT(DEC(PLAN))
            XDIST(DEC(PLAN)) = XDDIST(DEC(PLAN))
            XSPEED(DEC(PLAN)) = XSPEDI(DEC(PLAN))
            XD(DEC(PLAN)) = XDD(DEC(PLAN))
            XCOM(DEC(PLAN)) = 0
            MOPP(DEC(PLAN)) = 1
            TDC(DEC(PLAN)) = TDCON(DEC(PLAN))
            CFLAG(DEC(PLAN)) = 1
            XMOVE(DEC(PLAN)) = DTIME(PLAN)
            DO 590  TTD = TP,TEND,TSTEP
               ITTD = IFIX(TTD/TSTEP)
               XSIP(DEC(PLAN),ITTD) = XCSIP(DEC(PLAN),ITTD)
590        CONTINUE
            XTGTN(DEC(PLAN)) = 0
            IF (NCON .GT. 1) THEN
               DO 560  N = 1,NCON-1
                  IF (CONTAM(N) .EQ. DEC(PLAN)) THEN
                     DO 561  M = N,NCON-1
                        CONTAM(M) = CONTAM(M+1)
561                CONTINUE
                  END IF
560         CONTINUE
               NCON = NCON - 1
               NQ = NQ + 1
               STACK(NQ) = DEC(PLAN)
            ELSE
               NCON = 0
            END IF
         END IF
```

```
      IF (XTYPE(BLUE(PLAN)) .EQ. 3) THEN
         IF (TYPE(PLAN) .EQ. 'CHEM') THEN
            CRDS = CRDS - CHRDS
            IF (CRDS .LE. 0.)  CRDS = 1.
            CPC = CRDS/ARDS
         END IF
         DO 530  T3 = TIME(PLAN),(TIME(PLAN)+0.5),TSTEP
            ITT3 = IFIX(T3/TSTEP)
            FLAG3(BLUE(PLAN),ITT3) = 1
            Z(BLUE(PLAN)) = Z(BLUE(PLAN)) + 1
530      CONTINUE
      END IF
      IF (XTYPE(BLUE(PLAN)) .EQ. 4) THEN
         ITIMP = IFIX(TIME(PLAN)/TSTEP)
         END4 = XTA(BLUE(PLAN)) + 1. + (XDIST(BLUE(PLAN)) + YLOC(RED
     2        (PLAN),ITIMP))/XSPEED(BLUE(PLAN))
         DO 540  T4 = TIME(PLAN),END4,TSTEP
            ITT4 = IFIX(T4/TSTEP)
            FLAG4(BLUE(PLAN),ITT4) = 1
            Z(BLUE(PLAN)) = Z(BLUE(PLAN)) + 1
540      CONTINUE
      END IF
      IF (Z(BLUE(PLAN)).GE.((TDECN(PLAN)-TP)/TSTEP))
     2     XCOM(BLUE(PLAN)) = 1
      COM = 0
      DO 520  I = 1,NX
         IF (XCOM(I) .EQ. 1)  COM = COM + 1
520   CONTINUE
900   IF (COM .EQ. NX) THEN
         DO 910  TPOW = TP,TEND,TSTEP
            ITPOW = IFIX(TPOW/TSTEP)
            XTSIP(ITPOW) = XTSIPT(ITPOW)
            YTSIP(ITPOW) = YTSIPT(ITPOW)
910      CONTINUE
         PRINT *
         PRINT *,'Feasible plan not possible.  Request assistance'
         PRINT *,'      from higher HQ.'
         PRINT *
         PRINT *,'      Best plan found (but still not feasible): '
         PRINT *,'  TIME   BLUE UNIT  ON  RED UNIT   CHEM OR CONV'
         DO 570  N = 1,PLAN
            PRINT '(4X,F4.1,8X,I2,13X,I2,13X,A4)',  ENGAGE(N),BLUE(N),
     2           RED(N),TYPE(N)
            IF (DEC(N) .NE. 0) THEN
               PRINT *, 'T = ',DTIME(N),', BLUE unit ',DEC(N)
               PRINT *, 'begin move to decon site '
            END IF
570      CONTINUE
         PRINT *
         PRINT *,'   Enter time of update (hrs since T = 0)'
         PRINT *,'    (If none, enter 999 to terminate program)'
         READ *,  TP
         IF (TP .EQ. 999) GO TO 1000
         PRINT *,'At time T = ', TP
         GO TO 10
      END IF
      DO 510  TT = TP,TEND,TSTEP
         IT1 = IFIX(TT/TSTEP)
         XSIP1(BLUE(PLAN),IT1) = XSIP1T(BLUE(PLAN),IT1)
510   CONTINUE
      DO 580  JJ = 1,NY
         DO 581  TT = TP,TEND,TSTEP
            IT1 = IFIX(TT/TSTEP)
            YSIP1(JJ,IT1) = YSIP1T(JJ,IT1)
581      CONTINUE
```

```
580     CONTINUE
          XTGTN(BLUE(PLAN)) = XTGTN(BLUE(PLAN)) + 1
          YTGTN(RED(PLAN)) = YTGTN(RED(PLAN)) + 1
          XTGT(BLUE(PLAN),XTGTN(BLUE(PLAN))) = RED(PLAN)
          YTGT(RED(PLAN),YTGTN(RED(PLAN))) = BLUE(PLAN)
          XTENG(BLUE(PLAN),XTGTN(BLUE(PLAN))) = ENGAGE(PLAN)
          IF (TYPE(PLAN) .EQ. 'CHEM') THEN
             CONFL(BLUE(PLAN),XTGTN(BLUE(PLAN))) = 0
             CHEMFL(BLUE(PLAN),XTGTN(BLUE(PLAN))) = 1
          ELSE
             CONFL(BLUE(PLAN),XTGTN(BLUE(PLAN))) = 1
             CHEMFL(BLUE(PLAN),XTGTN(BLUE(PLAN))) = 0
          END IF
          TDEC = TDECN(PLAN)
          PLAN = PLAN + 1
          GO TO 320
        END IF
1000  STOP
        END
        SUBROUTINE POWER(NX,XK,XBIP,XDIST,XSPEED,XSTATE,XTGTN,XTGT,XATT,
     2 XCOM,XABIP,XSIP,XSIPTA,XTA,XTENG,NY,YK,YBIP,YDIST,YSPEED,YSTATE,
     3 YTGTN,YTGT,YABIP,YSIP,YATT,FEAS,TD,TP,TEND,TSTEP,TC,C,PERS,
     4 DECDIS,TDEC,TDMOVE,DECON,NQ,STACK,TDCON,XSPEDI,XSTATI,XD,YD,
     5 XTYPE,XTP,YTP,TU,XDISTI,YDISTI,CFLAG,YTA,TDC,XCATT,CONFL,CHEMFL,
     6 XTSIP,YTSIP,XTR,YDC,YTAC,YSPEDI,XMOVE)
**********************************************************************
*                                                                    *
*     THIS SUBROUTINE COMPUTES THE BLUE AND RED POWER CURVES AND     *
*     DETERMINES FEASIBILITY OR THE POINT OF INFEASIBILITY BY        *
*     COMPARING THEIR DIFFERENCE TO THE THRESHOLD VALUE.             *
*                                                                    *
**********************************************************************

**********************************
*    *** VARIABLE DECLARATIONS ***
**********************************

        INTEGER   NX,XTGTN(10),XTGT(0:10,0:25),XCOM(0:10),XTYPE(0:10)
        INTEGER   CFLAG(10),NY,YTGTN(10),YTGT(0:10,0:25),CONFL(10,0:25)
        INTEGER   FEAS,DECON,NQ,STACK(10),ITT,CHEMFL(10,0:25)
        REAL      XK(10),XBIP(10),XDIST(0:10),XSPEED(0:10),XSTATE(0:10)
        REAL      XATT(10,10),XABIP(0:10),XSIP(0:10,0:50),XSIPTA(10)
        REAL      XTENG(0:10,0:25),XMIN,XTSIP(0:50),XSPEDI(10),XD(0:10)
        REAL      XSTATI(10),XTP(10),XTA(0:10),XDISTI(10),XCATT,XTR(10)
        REAL      XSIP0,XMOVE(10)
        REAL      YK(10),YBIP(10),YDIST(10),YSPEED(10),YSTATE(10),YABIP(10)
        REAL      YSIP(0:10,0:50),YATT(10,10),YMIN,YTSIP(0:50),YD(10)
        REAL      YSIPTA(10),YTA(10),YTP(10),YDISTI(10),YDC(10),YTAC(10)
        REAL      YSIP0,YSPEDI(10)
        REAL      TD,TP,TEND,DIFF(0:50),CHATT(10),TC(10),C,TDMOVE
        REAL      TDCON(10),DECDIS,TDEC,ATT(10),TSTEP,TU,TDC(10)
        CHARACTER*1  PERS(10)
************************************************************************
*    *** COMPUTE ABIP'S, D'S (POWER GROWTH EXPONENT), TIMES OF ARRIVAL *
*         AT BATTLE POSITION ***                                       *
************************************************************************

        DO 5  I = 1,NX
          IF ((XDISTI(I) .GT. 0.).AND.(CFLAG(I) .EQ. 0)) THEN
            XABIP(I) = XBIP(I) * XK(I) * XSTATE(I) / XDISTI(I)
          END IF
          XSIPTA(I) = XBIP(I) * XK(I) * XSTATE(I)
5     CONTINUE
        DO 15  J = 1,NY
          IF (YDISTI(J) .GT. 0.) THEN
```

```
            YABIP(J) = YBIP(J) * YK(J) * YSTATE(J) / YDISTI(J)
         END IF
         YSIPTA(J) = YBIP(J) * YK(J) * YSTATE(J)
15    CONTINUE
*************************************************************
*    *** COMPUTE INDIVIDUAL POWER CURVES, EACH ENTITY ***
*************************************************************
*                      *** BLUE ***
*                      ************

       DO 105  I = 1,NX
         CHATT(I) = 1.

         YMIN = 9999.
         DO 106  J = 1,XTGTN(I)
            IF (YMIN .GT. XTENG(I,J))  YMIN = XTENG(I,J)
106     CONTINUE
*                     ****************************************************
*                        *** DETERMINE EFFECT OF DECON, IF NEEDED ***
*                     ****************************************************

         DO 115  T = TP,TEND,TSTEP
            ITT = IFIX(T/TSTEP)
            IF (PERS(I) .EQ. 'P') CHATT(I)=(SQRT(0.9*(EXP(-C*(T-TC(I))))
     2                                    *XSTATI(I)))*0.5/XSTATI(I)
            IF ((DECON .EQ. I).AND.(T .EQ. TDMOVE)) THEN
               IX = I
               CALL CHDCON(IX,XSTATE,TDCON,DECDIS,XDIST,
     2                 XSPEED,NO,STACK,TDEC,TDMOVE,TEND,TSTEP,C,
     3                 TC,XSTATI,XSIP,XD,XABIP,
     4                 XBIP,XK,XSPEDI,TP,XTENG,XTGTN,DECON)
               IF (DECON .NE. 0) GO TO 105
            END IF
*                     ************************************************
*                        *** DETERMINE POWER AT EACH TIME STEP ***
*                     ************************************************

            IF (T .LT. TDC(I)) GO TO 115

            IF (XTGTN(I) .EQ. 0) THEN
               IF (XDISTI(I) .EQ. 0) XABIP(I) = XBIP(I)*XK(I)*XSTATE(I)
               IF ((XDIST(I) .LT. XDISTI(I)).AND.(XDIST(I) .GT. 0.)) THEN
                  XSIP(I,ITT) = XABIP(I)*(EXP(XD(I)*((XDISTI(I)-XDIST(I))
     2                          /XSPEED(I))))* CHATT(I)
               ELSE
                  XSIP(I,ITT) = XABIP(I) * CHATT(I)
               END IF
               GO TO 115
            END IF

            ATT(I) = 0.
            DO 125  L = 1,XTGTN(I)
               IF (XCOM(I) .EQ. 0) THEN
                  IF (XTYPE(I) .EQ. 3) THEN
                     IF ((T .GT. XTENG(I,L)).AND.(T .LE. (XTENG(I,L)+0.5)))
     2                  THEN
                        ATT(I) = ATT(I) + YATT(I,XTGT(I,L))
                     END IF
                  ELSE IF (XTYPE(I) .EQ. 4) THEN
                     IF ((T .GT. XTENG(I,L)).AND.(T.LE.(XTENG(I,L)+1.)))THEN
                        ATT(I) = ATT(I) + YATT(I,XTGT(I,L))+ 0.03
                     END IF
                  ELSE
                     IF (T .GT. XTENG(I,L)) THEN
                        ATT(I) = ATT(I) + YATT(I,XTGT(I,L))
                     END IF
                  END IF
               ELSE
                  IF (T .GT. XTENG(I,L)) THEN
                     ATT(I) = ATT(I) + YATT(I,XTGT(I,L))
                  END IF
```

```
            END IF
 125     CONTINUE
           IF (T .EQ. TP) THEN
              IF (XTYPE(I) .EQ. 4) THEN
                 XSIP(I,ITT) = XSIPTA(I)* CHATT(I)
              ELSE IF (XTYPE(I) .EQ. 5) THEN
                 IF ((T .LT. XTA(I)).AND.(T .LT. XTP(I))) THEN
                    XSIP(I,ITT) =XABIP(I)*(EXP(XD(I)*((XDISTI(I)-XDIST(I))
     2                        /XSPEED(I)))) * CHATT(I)
                 ELSE IF (T .LT. XTA(I)) THEN
                    XSIP0 = XABIP(I)*(EXP(XD(I)*((XDISTI(I)-XDIST(I))
     2                   /XSPEED(I))))
                    XSIP(I,ITT) = XSIP0*(EXP(XD(I)*(T-XTP(I))))*CHATT(I)
                 ELSE IF (T .EQ. XTA(I)) THEN
                    XSIP(I,ITT) = XSIPTA(I)*CHATT(I)
                 ELSE IF ((T .GT. XTA(I)).AND.(T .LE. YMIN)) THEN
                    XSIP(I,ITT) = XSIPTA(I)*(EXP(-0.03*(T-XTA(I))))*CHATT(I)
                 ELSE
                    XSIP(I,ITT) = XSIPTA(I)*(EXP((-0.03-ATT(I))*(T-YMIN)))
     2                         *CHATT(I)
                 END IF
              ELSE
                 IF ((T .LT. XTR(I)).AND.(T .LT. XTP(I))) THEN
                    XSIP(I,ITT) = XABIP(I)*CHATT(I)
                 ELSE IF (T .LT. XTR(I)) THEN
                    XSIP(I,ITT) = XABIP(I)*(EXP(XD(I)*(T-XTP(I))))*CHATT(I)
                 ELSE IF (T .EQ. XTR(I)) THEN
                    XSIP(I,ITT) = XSIPTA(I)*CHATT(I)
                 ELSE IF ((T .GT. XTR(I)).AND.(T .LE. YMIN)) THEN
                    XSIP(I,ITT) = XSIPTA(I)*(EXP(-0.03*(T-XTR(I))))*CHATT(I)
                 ELSE
                    XSIP(I,ITT) = XSIPTA(I)*(EXP((-0.03-ATT(I))*(T-YMIN)))
     2                         *CHATT(I)
                 END IF
              END IF
           ELSE
              IF (XCOM(I) .EQ. 0) THEN
                 IF (XTYPE(I) .EQ. 3) THEN
                    IF (T .LT. XTR(I)) THEN
                       XSIP(I,ITT)=XSIP(I,ITT-1)*(EXP(XD(I)*TSTEP))*CHATT(I)
                    ELSE IF ((T .GE. XTR(I)).AND.(T .LE. YMIN)) THEN
                       XSIP(I,ITT)=XSIPTA(I)*(EXP(-0.03*(T-XTR(I))))*CHATT(I)
                    ELSE
                       XSIP(I,ITT) = XSIP(I,ITT-1)*(EXP((-0.03-ATT(I))*TSTEP
     2                           ))*CHATT(I)
                    END IF
                 ELSE IF (XTYPE(I) .EQ. 4) THEN
                    XSIP(I,ITT)=XSIP(I,ITT-1)*(EXP(-ATT(I)*TSTEP))*CHATT(I)
                 ELSE
                    IF (T .LT. XTP(I)) THEN
                       XSIP(I,ITT) = XABIP(I)*(EXP(XD(I)*((XDISTI(I)-XDIST(I)
     2                           )/XSPEED(I))))*CHATT(I)
                    ELSE IF (T .LE. XTA(I)) THEN
                       XSIP(I,ITT) = XSIP(I,ITT-1)*(EXP(XD(I)*TSTEP))
     2                           *CHATT(I)
                    ELSE
                       XSIP(I,ITT) = XSIP(I,ITT-1)*(EXP((-0.03-ATT(I))*TSTEP
     2                           ))*CHATT(I)
                    END IF
                 END IF
              ELSE
                 IF (T .LE. XTR(I)) THEN
                    XSIP(I,ITT) = XSIP(I,ITT-1)*(EXP(XD(I)*TSTEP))*CHATT(I)
                 ELSE
                    XSIP(I,ITT) = XSIP(I,ITT-1)*(EXP((-0.03-ATT(I))*TSTEP))
     2                       *CHATT(I)
                 END IF
              END IF
           END IF
```

```
115     CONTINUE
105   CONTINUE
*                 ***********
*                 *** RED ***
*                 ***********
        DO 155  J = 1,NY
          XMIN = 9999.
          DO 156  I = 1,YTGTN(J)
            DO 157  K = 1,XTGTN(YTGT(J,I))
              IF (XTGT(YTGT(J,I),K) .EQ. J) THEN
                IF (XMIN .GT. XTENG(YTGT(J,I),K))
     2            XMIN = XTENG(YTGT(J,I),K)
              END IF
157         CONTINUE
156       CONTINUE
          DO 165  T = TP,TEND,TSTEP
            ITT = IFIX(T/TSTEP)
            ATT(J) = 0.
            DO 166  I = 1,NX
              IF (T .LT. XMOVE(I)) THEN
              DO 167  K = 1,XTGTN(I)
                IF (XTGT(I,K) .EQ. J) THEN
                  IF (XCOM(I) .EQ. 0) THEN
                    IF (XTYPE(I) .EQ. 3) THEN
                      IF ((T .GT. XTENG(I,K)) .AND. (T .LE.
     2                         (XTENG(I,K)+0.5))) THEN
                ATT(J) = ATT(J) + XATT(J,I)*CONFL(I,K)+XCATT*CHEMFL(I,K)
                        IF (CHEMFL(I,K) .EQ. 1) THEN
                          YSPEED(J) = YSPEDI(J)/2.
                          YTA(J) = YTAC(J)
                          YD(J) = YDC(J)
                        END IF
                      END IF
                    ELSE IF (XTYPE(I) .EQ. 4) THEN
                      IF ((T .GT. XTENG(I,K)).AND.(T .LE.
     2                  (XTENG(I,K)+1.))) THEN
                ATT(J) = ATT(J) + XATT(J,I)*CONFL(I,K)+XCATT*CHEMFL(I,K)
                      END IF
                    ELSE IF (T .GT. XTENG(I,K)) THEN
                ATT(J) = ATT(J) + XATT(J,I)*CONFL(I,K)+XCATT*CHEMFL(I,K)
                    END IF
                  ELSE IF (T .GT. XTENG(I,K)) THEN
        ATT(J) = ATT(J) + XATT(J,I)*CONFL(I,K)+XCATT*CHEMFL(I,K)
                  END IF
                END IF
167         CONTINUE
              END IF
166       CONTINUE
            IF (T .EQ. TP) THEN
              IF ((T .LT. YTA(J)).AND.(T .LE. XMIN)) THEN
                YSIP(J,ITT) = YABIP(J) * (EXP(YD(J) * (T - YTP(J))))
              ELSE IF (T .LT. YTA(J)) THEN
                YSIP0 = YABIP(J)*(EXP(YD(J)*(XMIN-YTP(J))))
                YSIP(J,ITT) = YSIP0*(EXP((YD(J)-ATT(J))*(T-XMIN)))
              ELSE IF ((T .EQ. YTA(J)).AND.(T .LE. XMIN)) THEN
                YSIP(J,ITT) = YSIPTA(J)
              ELSE IF ( T .EQ. YTA(J)) THEN
                YSIP0 = YABIP(J)*(EXP(YD(J)*(XMIN-YTP(J))))
                YSIP(J,ITT) = YSIP0*(EXP((YD(J)-ATT(J)) * (T-XMIN)))
                YSIPTA(J) = YSIP(J,ITT)
              ELSE IF ((T .GT. YTA(J)).AND.(T .LE. XMIN)) THEN
                YSIP(J,ITT) = YSIPTA(J) * (EXP(-0.03 * (T - YTA(J))))
              ELSE
                YSIP0 = YSIPTA(J)*(EXP(-0.03*(XMIN-YTA(J))))
                YSIP(J,ITT) = YSIP0*(EXP((-0.03-ATT(J))*(T-XMIN)))
```

```
            END IF
         ELSE
            IF (T .LE. YTA(J)) THEN
               YSIP(J,ITT) = YSIP(J,ITT-1)*(EXP((YD(J)-ATT(J))*TSTEP))
            ELSE IF (T .GT. YTA(J)) THEN
               YSIP(J,ITT) = YSIP(J,ITT-1)*(EXP((-0.03-ATT(J))*TSTEP))
            END IF
         END IF
165     CONTINUE
155   CONTINUE
***************************************
*    *** COMPUTE TOTAL POWER CURVES ***
***************************************

       DO 205  T = TP,TEND,TSTEP
          ITT = IFIX(T/TSTEP)
          XTSIP(ITT) = 0.
          YTSIP(ITT) = 0.
          DO 215  I = 1,NX
             XTSIP(ITT) = XTSIP(ITT) + XSIP(I,ITT)
215     CONTINUE
          DO 225  J = 1,NY
             YTSIP(ITT) = YTSIP(ITT) + YSIP(J,ITT)
225     CONTINUE
          DIFF(ITT) = XTSIP(ITT) - YTSIP(ITT)
205   CONTINUE
**********************************
*    *** DETERMINE FEASIBILITY ***
**********************************

       DO 250  T = TP,TEND,TSTEP
          ITT = IFIX(T/TSTEP)
          IF (DIFF(ITT) .LE. TU) THEN
             FEAS = 0
             TD = T
             GO TO 1000
          ELSE
             FEAS = 1
             TD = TEND
          END IF
250   CONTINUE
1000  RETURN
       END
       SUBROUTINE CHDEF(XTHRT,MOPP,C,CONTAM,NCON,NX,XK,XBIP,XDIST,XSPEED,
     2                  XSTATE,XTGTN,XTGT,XATT,XCOM,XABIP,XSIP,XSIPTA,
     3                  XTA,XTENG,NY,YK,YBIP,YDIST,YSPEED,YSTATE,YTGTN,
     4                  YTGT,YABIP,YSIP,YATT,FEAS,TD,TP,TEND,TSTEP,TC,
     5                  PERS,DECDIS,TDEC,TDMOVE,DECON,NQ,STACK,TDCON,
     6                  XSPEDI,XSTATI,XD,YD,XTYPE,XTP,YTP,TU,XDISTI,
     7                  YDISTI,CFLAG,YTA,TDC,XCATT,CONFL,CHEMFL,XTSIP,
     8                  YTSIP,XTR,YDC,YTAC,YSPEDI,XMOVE)
*****************************************************************
*                                                               *
*    THIS SUBROUTINE USES THE PERCEIVED CHEMICAL THREAT TO      *
*    DETERMINE THE APPROPIATE MOPP LEVEL AND THE COMMENSURATE   *
*    OPERATIONAL DEGRADATION, CONSIDERING EFFECT ON THE MISSION, *
*    BY COMPARING THE RESULTING POWER CURVES; AND IDENTIFIES    *
*    CONTAMINATED UNITS OR UNITS UNDER CHEMICAL ATTACK          *
*                                                               *
*****************************************************************

**********************************
*    *** VARIABLE DECLARATIONS ***
**********************************

       INTEGER  XTHRT(10),MOPP(10),CONTAM(10),NCON,NX,XTGTN(10)
       INTEGER  XTGT(0:10,0:25),XCOM(0:10),CFLAG(10),XTYPE(0:10)
       INTEGER  NY,YTGTN(10),YTGT(0:10,0:25),CONFL(10,0:25)
```

```
      INTEGER  FEAS,DECON,NQ,STACK(10),CHEMFL(10,0:25)
      REAL     XK(10),XBIP(10),XDIST(0:10),XSPEED(0:10),XSTATE(0:10)
      REAL     XATT(10,10),XABIP(0:10),XSIP(0:10,0:50),XSIPTA(10)
      REAL     XTENG(0:10,0:25),XSPEDI(10),XSTATI(10),XD(0:10),XMOVE(10)
      REAL     XTP(10),XTA(0:10),XDISTI(10),XCATT,XTSIP(0:50),XTR(10)
      REAL     YK(10),YBIP(10),YDIST(10),YSPEED(10),YSTATE(10),YABIP(10)
      REAL     YSIP(0:10,0:50),YATT(10,10),YD(10),YTP(10),YDISTI(10)
      REAL     YTSIP(0:50),YDC(10),YTAC(10),YSPEDI(10)
      REAL     TD,TP,TEND,TC(10),C,TDMOVE,TDCON(10),DECDIS,TDEC,TSTEP
      REAL     TU,YTA(10),TDC(10)
      CHARACTER*1  PERS(10)
*****************************************
*     *** SET MOPP INDICATED BY THREAT ***
*****************************************
      NCON = 0
      DO 100  I = 1,NX
         IF (XTHRT(I) .EQ. 6) THEN
            MOPP(I) = 4
            IF (PERS(I) .EQ. 'P') THEN
               NCON = NCON + 1
               CONTAM(NCON) = I
            END IF
         ELSE IF (XTHRT(I) .EQ. 5) THEN
            MOPP(I) = 3
         ELSE IF (XTHRT(I) .EQ. 4) THEN
            MOPP(I) = 2
         ELSE IF (XTHRT(I) .EQ. 3) THEN
            MOPP(I) = 1
         ELSE
            MOPP(I) = 0
         END IF
100   CONTINUE
*********************************************
*     *** DEGRADE PERFORMANCE DUE TO MOPP ***
*********************************************
10    DO 200  I = 1,NX
         IF (MOPP(I) .EQ. 4) THEN
            XSTATE(I) = XSTATI(I) * 0.5
            XSPEED(I) = XSPEDI(I) * 0.5
         ELSE IF (MOPP(I) .EQ. 3) THEN
            XSTATE(I) = XSTATI(I) * 0.75
            XSPEED(I) = XSPEDI(I) * 0.75
         ELSE IF (MOPP(I) .EQ. 2) THEN
            XSTATE(I) = XSTATI(I) * 0.95
            XSPEED(I) = XSPEDI(I)
         ELSE
            XSTATE(I) = XSTATI(I)
            XSPEED(I) = XSPEDI(I)
         END IF
200   CONTINUE
***********************************************************
*     *** CHECK FEASIBILITY. IF INFEASIBLE, ADJUST MOPP ***
***********************************************************
      TDMOVE = 0.
      DECON = 0
      CALL POWER(NX,XK,XBIP,XDIST,XSPEED,XSTATE,XTGTN,XTGT,XATT,XCOM,
     2           XABIP,XSIP,XSIPTA,XTA,XTENG,NY,YK,YBIP,YDIST,YSPEED,
     3           YSTATE,YTGTN,YTGT,YABIP,YSIP,YATT,FEAS,TD,TP,TEND,TSTEP,
     4           TC,C,PERS,DECDIS,TDEC,TDMOVE,DECON,NQ,STACK,TDCON,
     5           XSPEDI,XSTATI,XD,YD,XTYPE,XTP,YTP,TU,XDISTI,YDISTI,
     6           CFLAG,YTA,TDC,XCATT,CONFL,CHEMFL,XTSIP,YTSIP,XTR,
     7           YDC,YTAC,YSPEDI,XMOVE)
```

```
      IF (FEAS .EQ. 0) THEN
        ICT = 0
        DO 250  I = 1,NX
          IF (MOPP(I) .LE. 2)  ICT = ICT + 1
          IF (XTHRT(I) .EQ. 6)  ICT = ICT + 1
250     CONTINUE
        IF (ICT .EQ. NX)  GO TO 900
        DO 300  I = 1,NX
          IF ((MOPP(I) .GT. 2).AND.(XTHRT(I) .NE. 6)) THEN
            MOPP(I) = MOPP(I) - 1
          END IF
300     CONTINUE
        GO TO 10
      END IF
*****************************************
*   *** OUTPUT MOPP RECOMMENDATIONS ***
*****************************************

900   PRINT *
      PRINT *,'   Recommended MOPP: '
      DO 400  I = 1,NX
        PRINT *,'BLUE unit',I ,',',' MOPP', MOPP(I)
400   CONTINUE
      RETURN
      END
      SUBROUTINE CHEMP(J,T,YSPEED,YSPEDI,YDC,YTAC,YLOC,YTYPE,TSTEP,
     2                  CHRDS,ITT,XCATT,YDISTI)
***********************************************************************
*                                                                     *
*     THIS SUBROUTINE PLANS BLUE CHEMICAL STRIKES.  FOR POTENTIAL     *
*     TARGETS, DETERMINES NO. ROUNDS REQUIRED, EFFECTS (ATTRITION     *
*     COEFFICIENT).                                                   *
*                                                                     *
***********************************************************************

**********************************
*     *** VARIABLE DECLARATIONS ***
**********************************

      INTEGER  YTYPE(10),ITT
      REAL     YSPEED(10),YSPEDI(10),YDC(10),YTAC(10)
      REAL     YLOC(0:10,0:50),TSTEP,CHRDS,EFF1,T,XCATT,YDISTI(10)
      DATA  EFF1/0.575/
********************************************
*     *** DETERMINE NO. OF ROUNDS REQUIRED ***
********************************************

      IF ((YTYPE(J) .EQ. 1).OR.(YTYPE(J) .EQ. 2)) THEN
        CHRDS = 144.
      ELSE
        CHRDS = 108.
      END IF
******************************
*     *** DETERMINE EFFECTS ***
******************************

      XCATT = -(LOG(EFF1))/0.5
      YSPEED(J) = YSPEDI(J)/2.
      IF (YLOC(J,ITT) .GT. 0.) THEN
        YTAC(J) = (YLOC(J,ITT)/YSPEED(J)) + T
        YDC(J) = (LOG(YDISTI(J)))/(YDISTI(J)/YSPEED(J))
      END IF
      RETURN
      END
      SUBROUTINE CHDCON(I,XSTATE,TDCON,DECDIS,XDIST,
     2                  XSPEED,NQ,STACK,TDEC,TDMOVE,TEND,TSTEP,C,
```

```
     3                   TC,XSTATI,XSIP,XD,XABIP,
     4                   XBIP,XK,XSPEDI,TP,XTENG,XTGTN,DECON)
**********************************************************************
*                                                                    *
*     THIS SUBROUTINE COMPUTES POWER CURVES FOR SELECTED CONTAMINATED*
*     BLUE UNITS THROUGH MOVEMENT TO DECON SITE, DECONTAMINATION, AND*
*     RESETS PARAMETERS ACCORDINGLY, RESTORING UNIT TO PRE-          *
*     CONTAMINATED STATE AND MAKING IT AVAILABLE FOR RECOMMITMENT    *
*     IN FUTURE COURSES OF ACTION.                                   *
*                                                                    *
**********************************************************************

***********************************
*     *** VARIABLE DECLARATIONS ***
***********************************

      INTEGER  NQ,STACK(10),ITT,ITP,XTGTN(10),DECON
      REAL     XBIP(10),XK(10),XSPEDI(10),XT(10),XSTATE(0:10)
      REAL     DECDIS,XDIST(0:10),XSPEED(0:10),TDEC,TDMOVE,TEND
      REAL     TSTEP,CHATT(10),C,TC(10),XSTATI(10),XSIP(0:10,0:50)
      REAL     XABIP(0:10),TDCON(10),TP,TDECON(10),XD(0:10)
      REAL     XTENG(0:10,0:25),CXABIP(10),XCABIP(10)
**********************************************************************
*     *** DETERMINE ARRIVAL, DEPARTURE TIMES AT DECON SITE.  IF MORE*
*        THAN ONE UNIT AT SITE, DELAY DECON UNTIL PREVIOUS UNIT      *
*        CLEAR ***                                                   *
**********************************************************************

      TDECON(I) = (ABS(DECDIS - XDIST(I)))/XSPEED(I) + TDMOVE

      IF (NQ .GE. 1) THEN
         DO 10  M = 1,NQ
            IF ((TDECON(I) .GE. TDECON(STACK(M))).AND.(TDECON(I) .LT.
     2          TDCON(STACK(M)))) THEN
               TDECON(I) = TDCON(STACK(M))
            END IF
10       CONTINUE
      END IF

      TDCON(I) = TDECON(I) + 4.

      IF (TDCON(I) .GT. TEND) THEN
         TDCON(I) = TEND
         DECON = 0
         GO TO 1000
      END IF
*******************************************************
*     *** COMPUTE POWER CURVE FOR DECONTAMINATED UNIT ***
*******************************************************

      XSTATE(I) = SQRT(0.9*(EXP(-C*(TDECON(I)-TC(I))))*XSTATI(I))

      DO 100  T = TDMOVE,TEND,TSTEP
         ITT = IFIX(T/TSTEP)
         CHATT(I) = (SQRT(0.9*(EXP(-C*(T-TC(I))))*XSTATI(I)))*0.5/
     2              XSTATI(I)
         IF (T .EQ. TP) THEN
            XSIP(I,ITT) = XBIP(I)*XK(I)*XSTATI(I)*(EXP((-0.03-0.05)*
     2                    (T-2.)))
         ELSE IF ((T .LT. TDECON(I)).AND.(T .GT. TP)) THEN
            XSIP(I,ITT) = XSIP(I,ITT-1)*CHATT(I)*(EXP(-XD(I)*(T-TDMOVE)))
         ELSE IF (T .EQ. TDECON(I)) THEN
            XDIST(I) = DECDIS
            CXABIP(I) = XBIP(I)*XK(I)*XSTATI(I)*CHATT(I)/(0.5*XDIST(I))
            XCABIP(I) = XBIP(I)*XK(I)*XSTATE(I)/XDIST(I)
            XSIP(I,ITT) = CXABIP(I)
            XD(I) = (LOG(XDIST(I)))/(XDIST(I)/XSPEDI(I))
            XT(I) = (LOG(XCABIP(I)/CXABIP(I)))/4.
         ELSE IF (T .LE. TDCON(I)) THEN
            XSIP(I,ITT) = CXABIP(I)*(EXP(XT(I)*(T-TDECON(I))))
         ELSE
            XSIP(I,ITT) = XSIP(I,IFIX(TDCON(I)/TSTEP))
```

```
          XABIP(I) = XSIP(I,ITT)
        END IF
100   CONTINUE
1000  RETURN
       END
```

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